Overview of SMOS Land Activities

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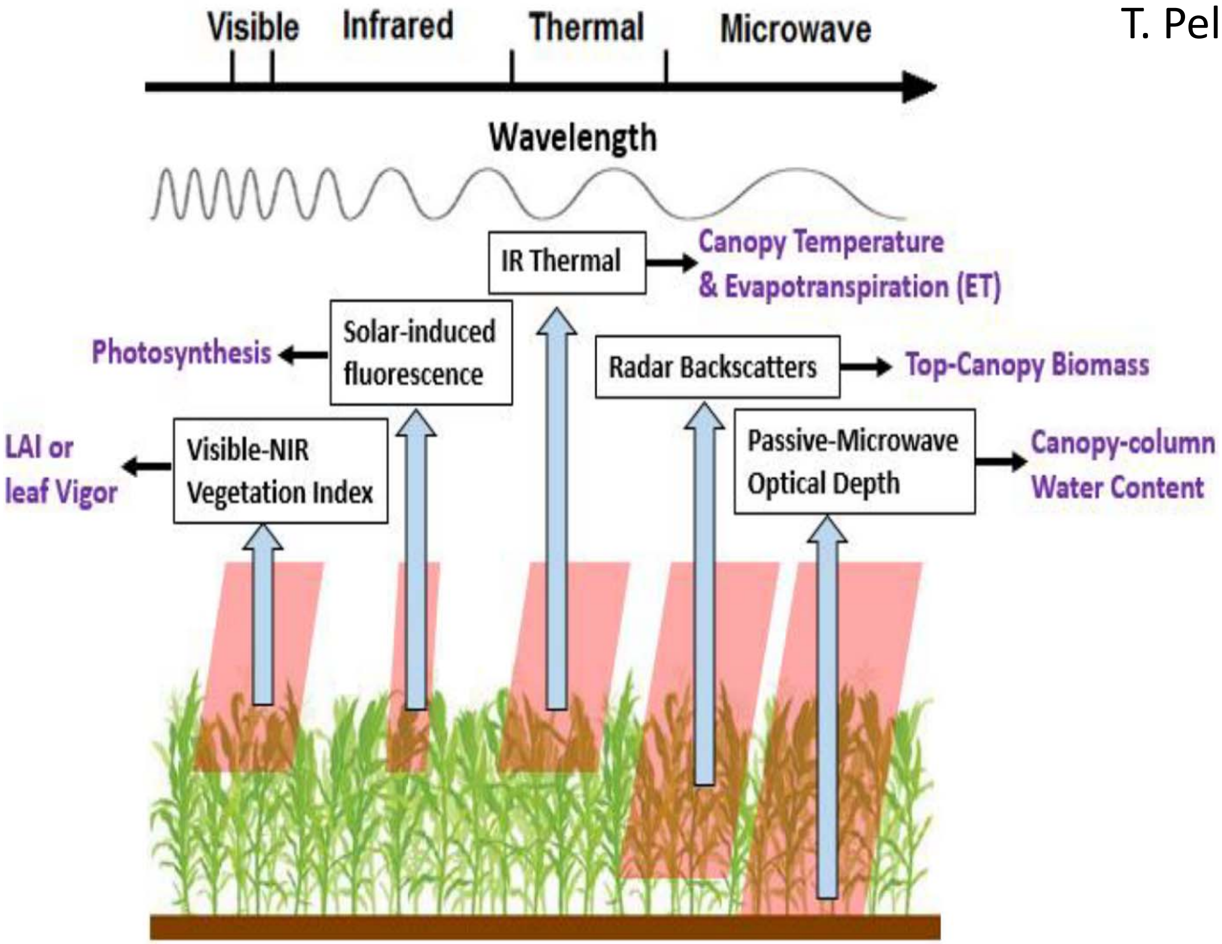
Jean Pierre Wigneron, Thierry Pellarin, Paolo Ferrazzoli, Mike Schwank
and the SMOS team
CESBIO, INRA-ISPA, TVU, ECMWF, WSL, LTHE, …

Foreword

- ❑ Workshop ➔ interrupt me when you do not agree
  - ❖ provocative
- ❑ For L band, time is the essence
  - ❖ L band continuation is at risks
  - ❖ Without a follow on we may loose this measurement tools
    - ➢ Frequency allocations!
- ❑ L band was based to fulfil your requirements
  - ❖ Many others things as well while others emerged but….
- ❑ Back to some basic facts first

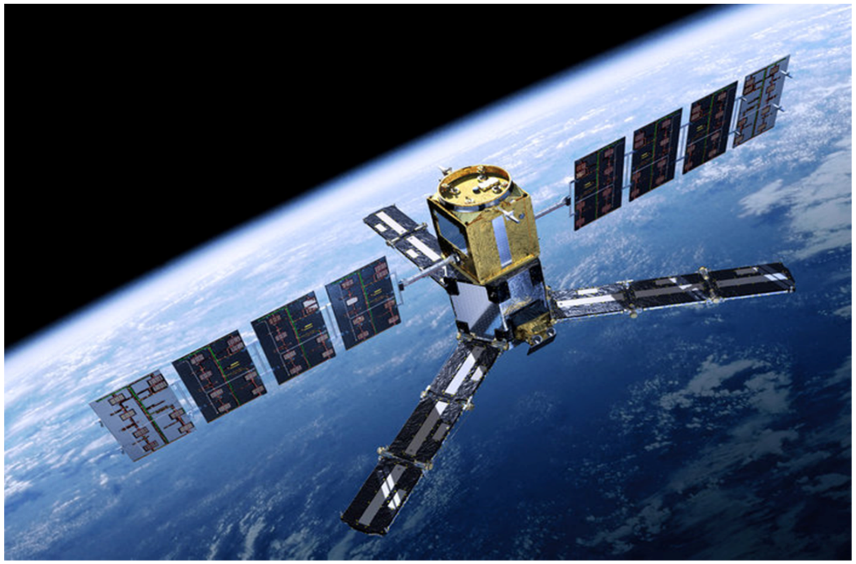
Use of Microwave radiometry : vegetation example

T. Pellarin



Optical wavelengths have been used for a long time to derive water stress , droughts or yield estimates. Trials were done with active microwaves (radar) with mitigated successes. Passive microwaves have shown potential but only recently low frequencies (L band) have been available and have shown very important and promising first results

ESA's Soil Moisture and Ocean Salinity Mission



- ❑ In orbit since 2nd November 2009 and in **excellent technical conditions**
- ❑ **Guranteed mission operations until 2019** ...
  technical limits to operate mission ...
- ❑ Measurement principle ... Imaging Radiome... instrument): pa... **interferometric radi...** ...
  (1.4GHz, 21cm)
- ❑ Orbit - ~ altitude o... km; inclination of 98.44° ; low-Earth orbit, polar, sun-synchronous

SUPPORTING LARGE VARIETY OF LAND APPLICATION:

Agriculture
- ❑ New: Soil moisture in near-real time (neural network approach)
- ❑ High resolution soil moisture products
- ❑ Root-zone soil moisture
- ❑ Drought index
- ❑ Food security
- ❑ Vegetation Optical Depth
- ❑ Soil freeze and thaw

Hazards
- ❑ Fires
- ❑ ...

... soil moisture in hydrological models
... fraction and river discharge

Weather forecasting
- ❑ **SMOS in NWP**

Climate
- ❑ Climate Change Initiative: soil moisture

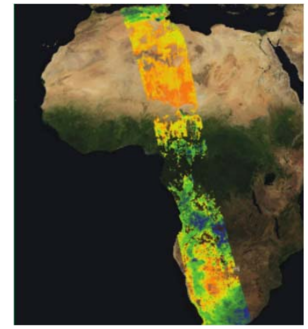
DATA ACCESS
ESA: http://smos-diss.eo.esa.int/
CATDS www.catds.fr/Products/Available-products-from-CPDC
BEC: http://cp34-bec.cmima.csic.es/land-datasets

SMOS DATA PRODUCTS
Over land

DATA ACCESS
ESA: http://smos-diss.eo.esa.int/
CATDS www.catds.fr/Products/Available-products-from-CPDC
BEC: http://cp34-bec.cmima.csic.es/land-datasets

Operational / NRT products / Latency < 3 hours

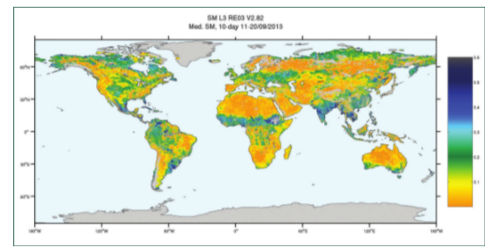
Data product	Resolution/format	Latency	Available from
NRT light: Level 1 brightness temperature	30-50km (N256 Gaussian grid), swath based; BUFR.	NRT/ 3 hours from sensing	ESA EUMETCAST WMO GTS
Level 2 soil moisture in NRT (based on Neural Network)	15 km (ISEA 4H9 grid), swath based; NETCDF.	NRT/~4 hours from sensing	



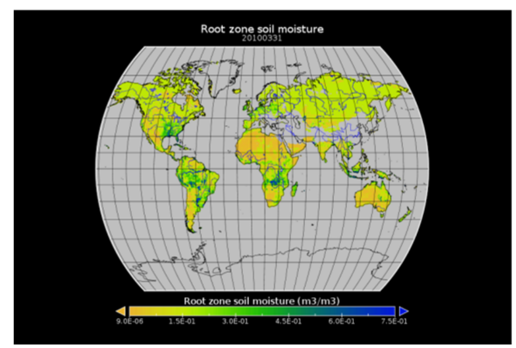
SMOS swath-based L2 soil moisture product. Credits ESA

Science and composite products / Latency > 3 hours

Data product	Resolution/format	Latency	Available from
Level 1 brightness temperature	15 km (ISEA), swath EEF /NetCDF. 25 km, global, EASE- NetCDF	6-8 hours after sensing 1 d after sensing	ESA CATDS(+ stereopolar)
Level 2 Soil moisture	15 km (ISEA), swath EEF /NetCDF. 25 km, global, EASE- NetCDF	8-12 hours 1 d	ESA CATDS
Level 3 Brightness Temperature and Soil Moisture	15 km (ISEA 4H9) grid/ 25 km (EASE) grid depending on product. NETCDF	Daily, 3, 9 days, weekly, monthly	CATDS BEC
Level 4 fine-scale soil moisture	1 km, for Iberian Peninsula; NETCDF 1 km for MODIS Tiles	2 daily maps (one asc/ one desc) in NRT	BEC CATDS (2017)
Level 4 CATDS Root Zone Soil Moisture	~25 km (EASE grid version 2); NetCDF	Daily, 10 days, monthly	CATDS
Level 4 Drought Index	25 km EASE 2 grid netcdf	Daily, 10 day, Monthly	CATDS
Freeze and thaw	~25 km (EASE grid version 2); NetCDF, Northern Hemisphere	Daily	Demo data set available from FMI
Surface roughness	25 km NETCDF, global	Yearly	CATDS



10-day global composite of L3 soil moisture. Credits CATDS/CESBIO



Root zone soil moisture in m^3/m^3. Credits CATDS/CESBIO

SMOS Mission

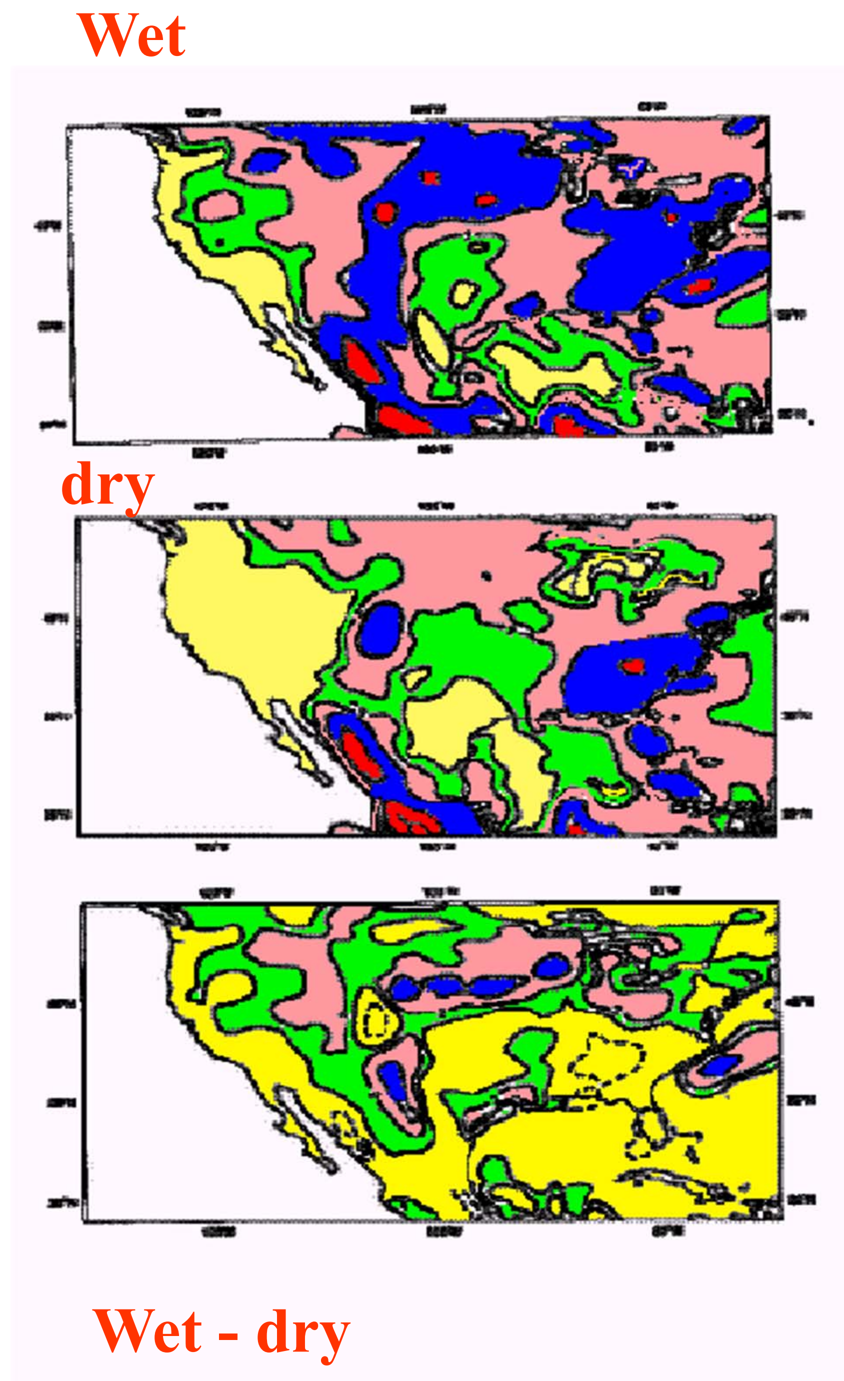
- ❑ Launched in 2009
  - ❖ data flow started in January 2010
  - ❖ Works perfectly since end of commissioning phase
    - ➢ SMOS SMAP Complementarity
  - ❖ Fulfills requirements
- ❑ Several re-processings
  - ❖ New measurements & new instrument ➔ wax and strings, trial and error approach to overcome the unexpected !
  - ❖ Many improvements from V3 to V6, V7 underway!
- ❑ Availability of L2 and L3 -L4, new products in the making
- ❑ Question after almost 8 years: how useful is L band radiometry? Why not used in NWP?
- ❑ Memories…

Improving forecasts

- Soil moisture impact in NWP
- Precipitations example

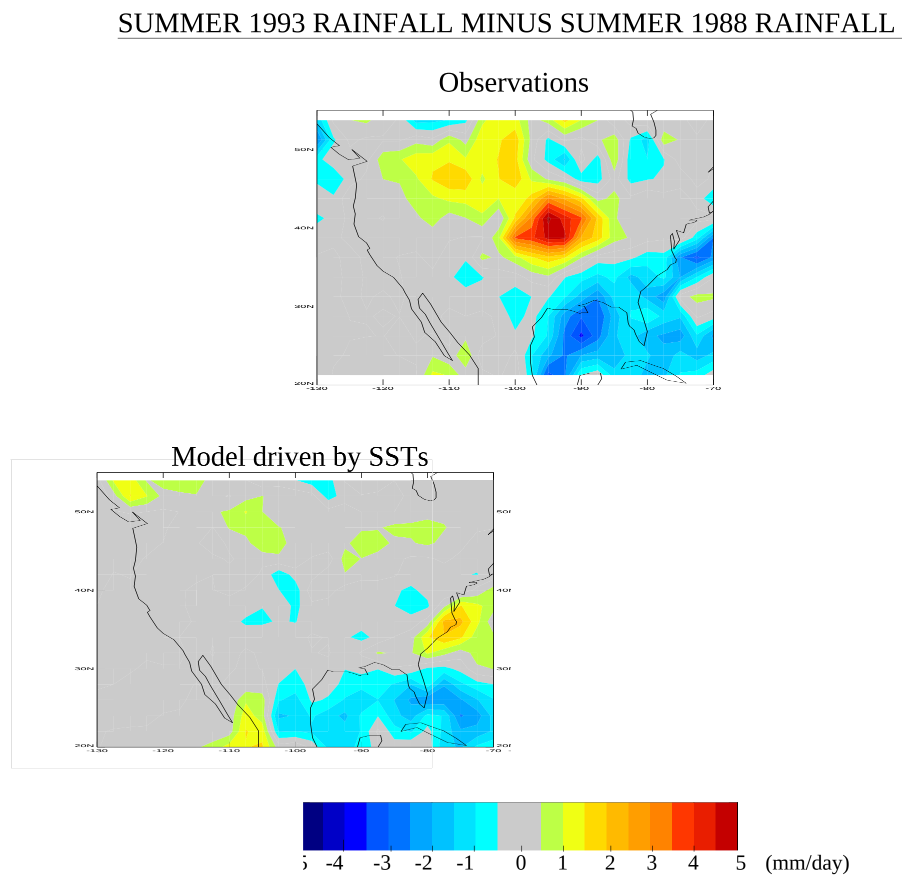
0-1 mm/j
1-2 mm/j
2-4 mm/j
4-8 mm/j
>8 mm/j

AK Betts 19??



Role of Soil moisture in surface atmosphere interactions

- •storage of water (surface and root zone),
- •water uptake by vegetation (root zone),
- •fluxes at the interface (evaporation),
- •influence on run-off



Predictability of seasonal climate is dependent on boundary conditions such as SST and soil moisture. In this sensitivity study it is shown that modelled summertime regional rainfall is more a function of soil moisture than SST boundary specifications.

Impact on forecasted precipitation

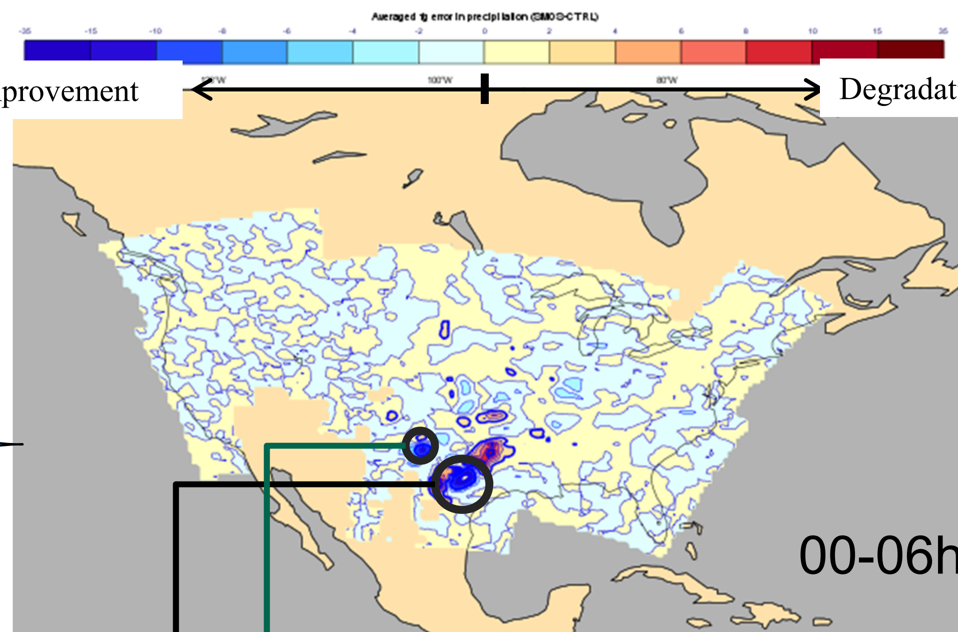
- “Truth”: 6h accumulated precipitation from radar observations of the NEXRAD network,

- Target variable: fg-departure fc error;

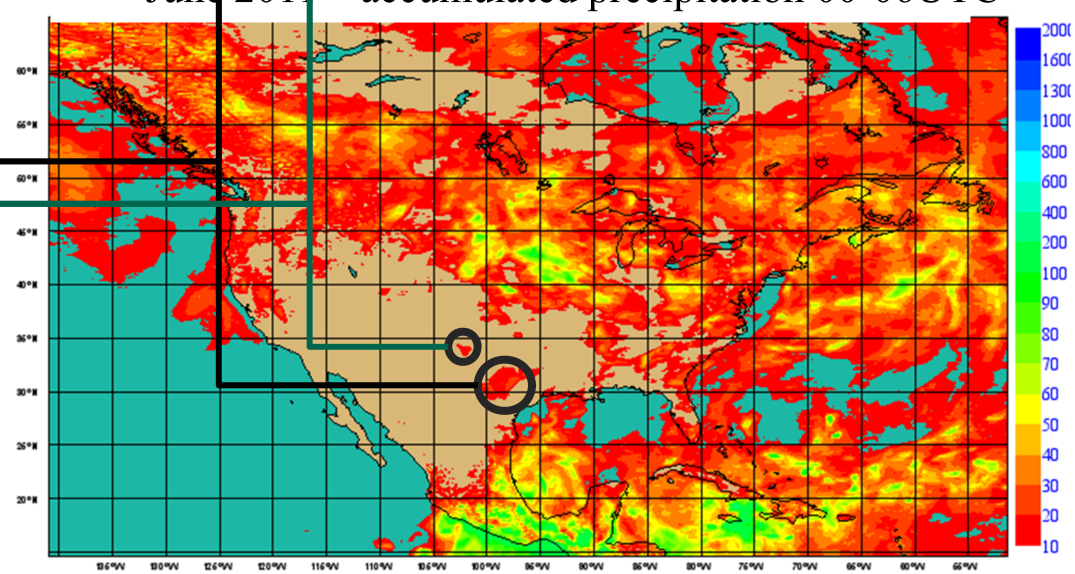
Impact 6h fc= $(OBS_{00\text{-}06}\text{-}fc_{06})_{EXPT} - (OBS_{00\text{-}06}\text{-}fc_{06})_{CTRL}$

OBS → 06 → 12 → 18 → 24

fc06h →



June 2011 – accumulated precipitation 00-06UTC

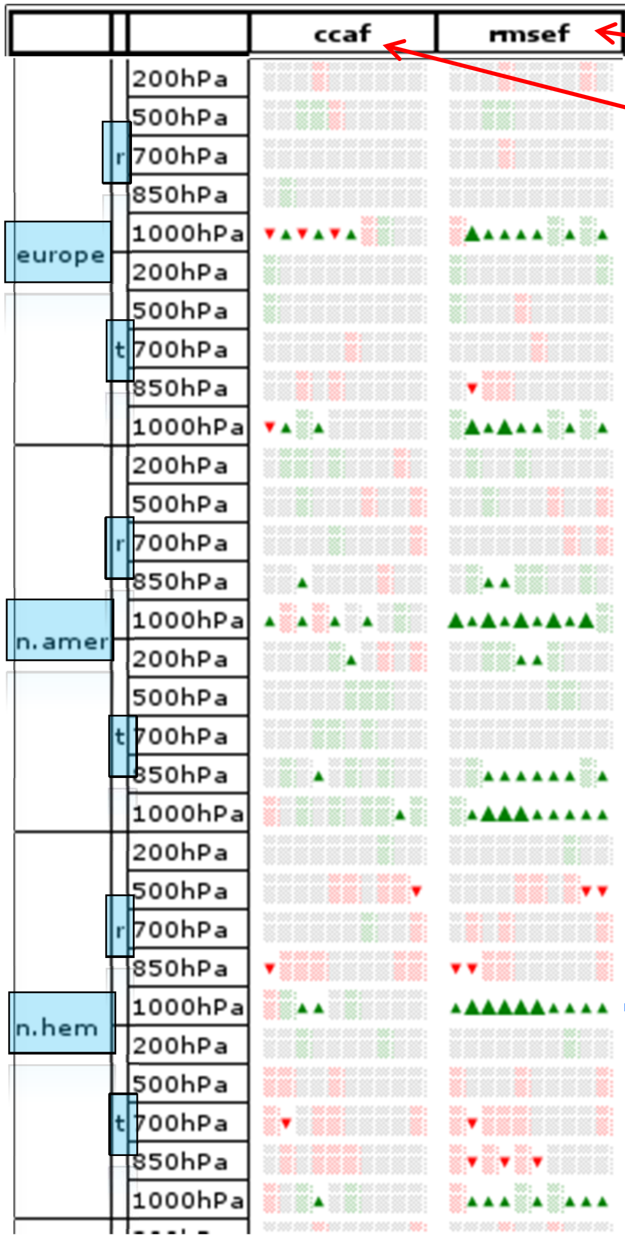


June 2011 → The two areas with the largest improvements in forecasted precipitation (for the period 00-06h), coincide with two isolated convective cumulus of precipitation.

Impact of the fc precipitation limited to the first 12h fc.

J. Munoz-Sabater

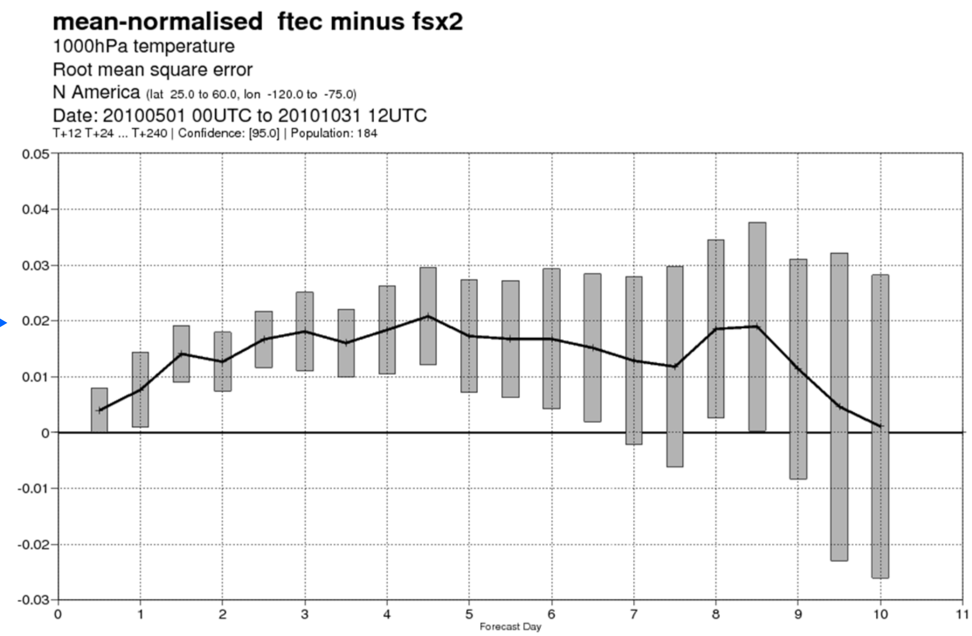
Verification on air temperature and humidity



Root-mean square forecast error

Anomaly correlation forecast

Summer-2010
(Jun, Jul, Aug)



J. Munoz-Sabater

SMOS in DATA ASSIMILATION

new observation systems | **novel measurements**

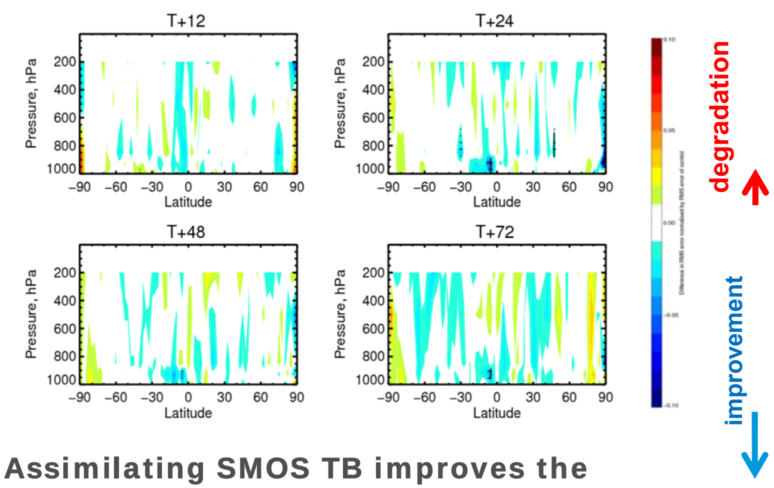
data assimilation

high quality analyses and improved initial conditions

forecast

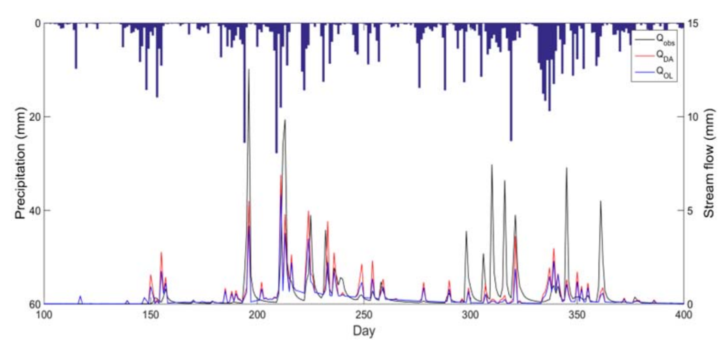
increased predictive skill | **improved risk mitigation** | **societal benefit**

NWP – ASSIMILATING SMOS TB



Assimilating SMOS TB improves the soil moisture analysis. The impact on weather is neutral to positive (blue) (ECMWF)

PREDICTING STREAMFLOW

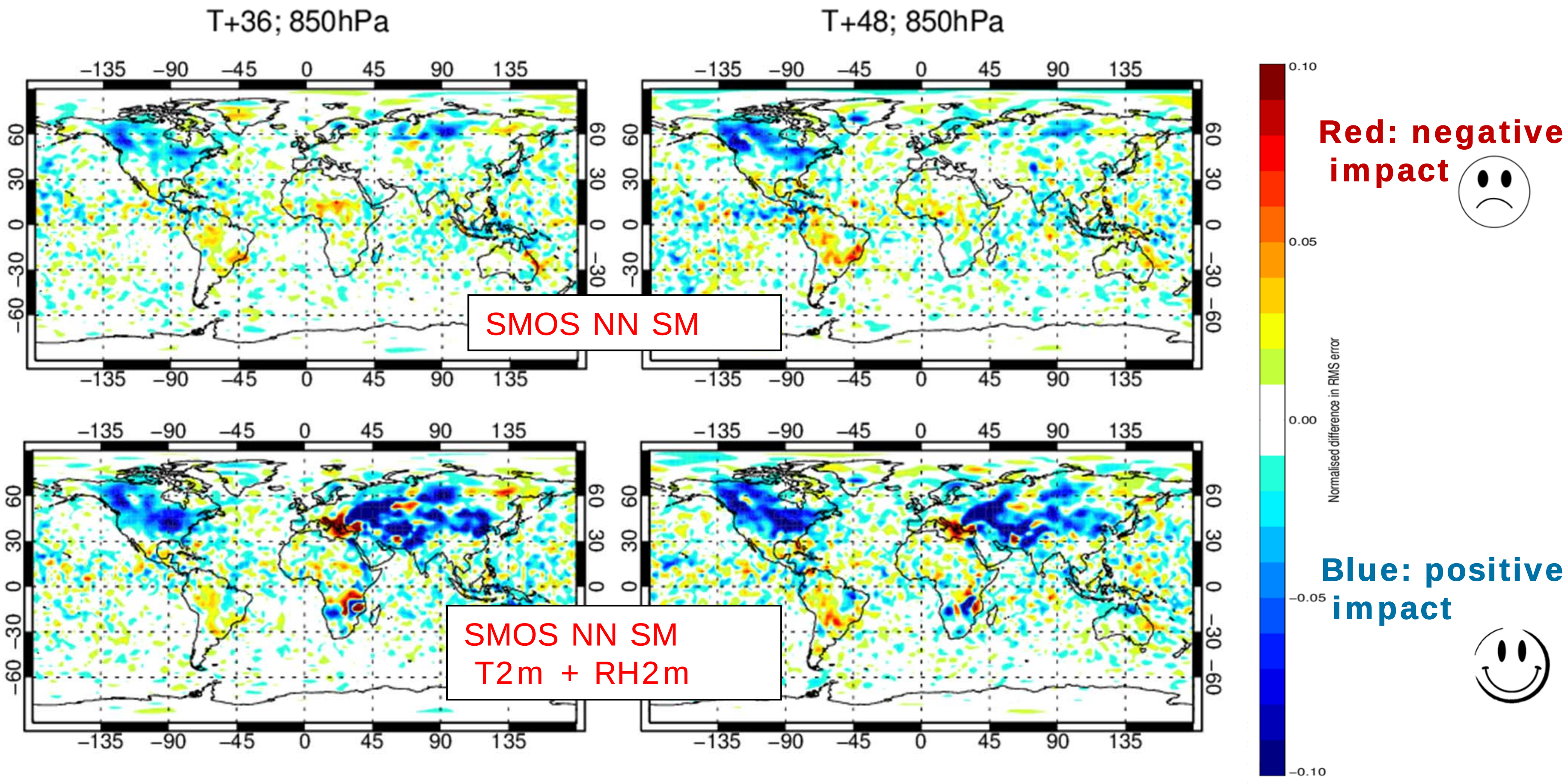


The impact on stream flow is positive. (U. Gent)

SMOS neural network soil moisture for ECMWF data assimilation

Approach

Rodriguez-Fernandez, de Rosnay, Albergel et al



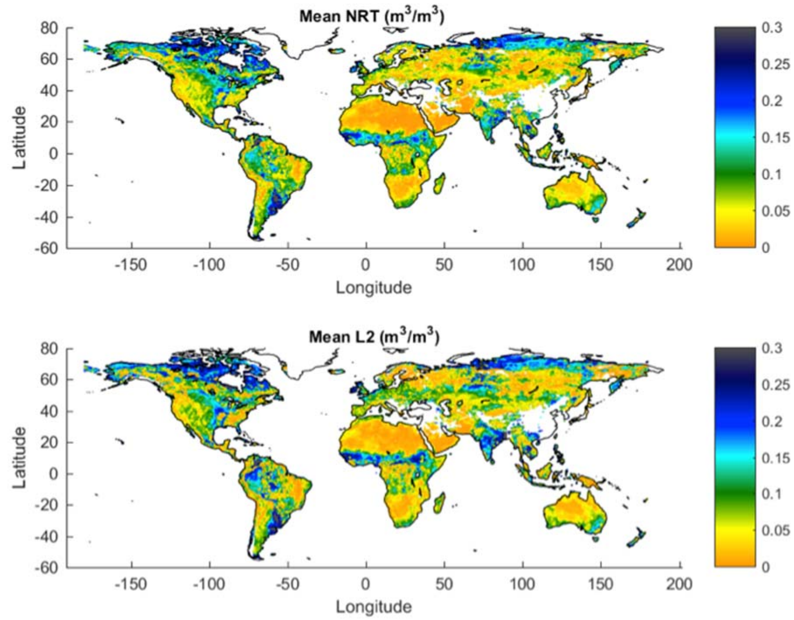
New level 2 SMOS NRT Soil Moisture product based on Neural Networks

Designed by CESBIO/Estellus, Implemented by ECMWF

- Neural Network used to retrieve SMOS L2 SM from NRT brightness temperature
- Trained on SMOS L2 Soil moisture

→ NRT (~3h latency) SMOS L2 SM

- Available in NetCDF, since March 2016 on ESA SMOS Online Dissemination servicehttps://smos-ds-02.eo.esa.int/oads/access
  also on EUMETCAST and GTS



Comparison between L2 NRT and L2 v6.20 soil moisture

Evaluation against in situ stations (USCRN and SCAN)
→ median correlation of 0.71

L band and NWP

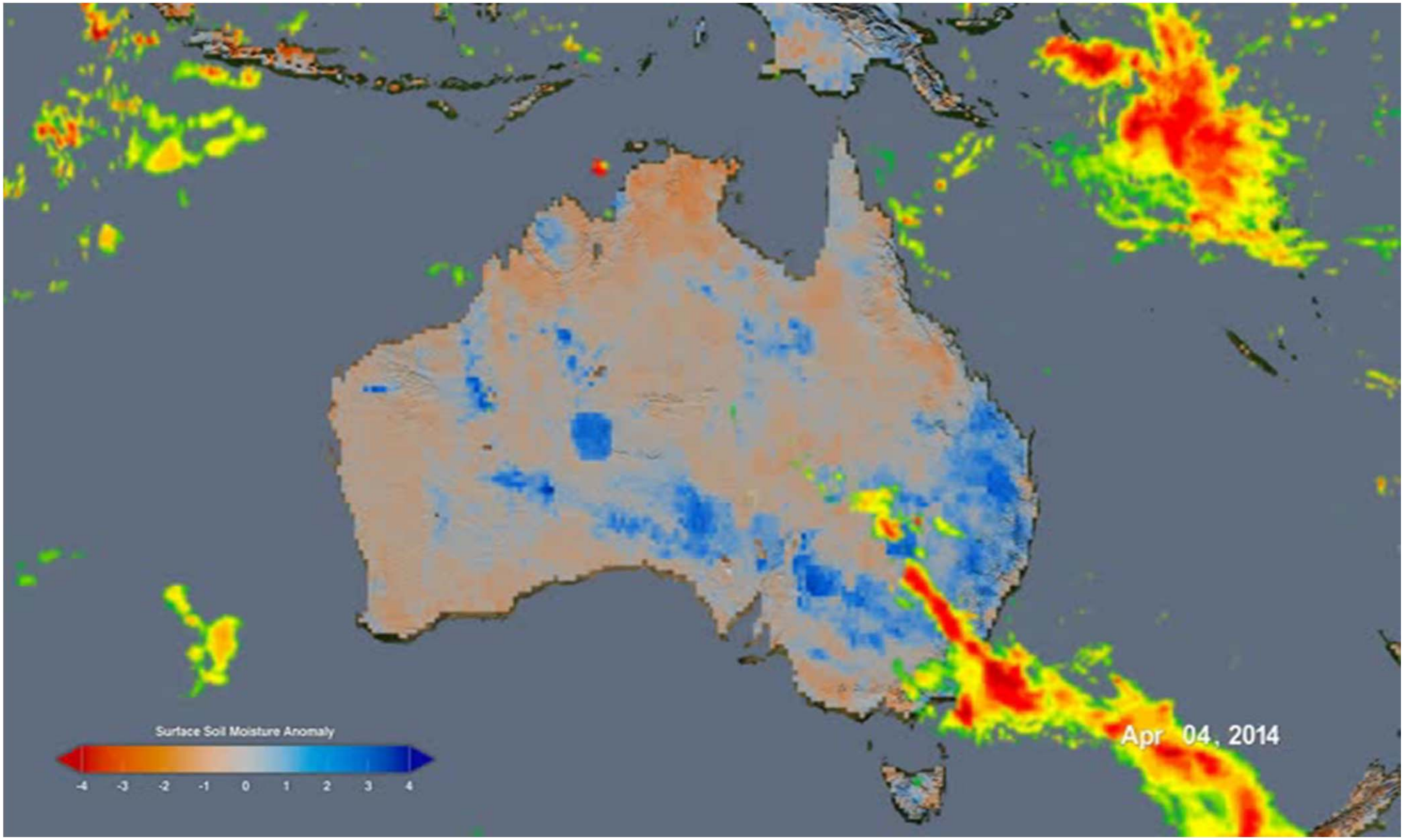
- Used as first guess, for monitoring and for reanalysis (De Rosnay yesterday)
- High potential demonstrated for extreme events
- Positive impact (Note that ASCAT neutral as it is scaled by the same models!)
  - Lost key syndrome
  - But good salesmanship

So what is issue?

- ❑ Data availability?
  - ❖ No SMOS + SMAP= daily
- ❑ data continuity?
  - ❖ No → in your hands
- ❑ Data quality?
  - ❖ NO to my analysis
- ❑ Approach?
  - ❖ Data to fit model rather than using data…
- ❑ Model issues ?
  - ❖ Humm well….
  - ❖ It shows issues in their modelling which have to be corrected
- ❑ Other?
  - ❖ …
- ❑ Issues
  - ❖ NWP centres wait for follow-ons to fully implement
  - ❖ Agencies ready to make follow on if NWP centres use it

SMOS and Precipitations (IMERG)

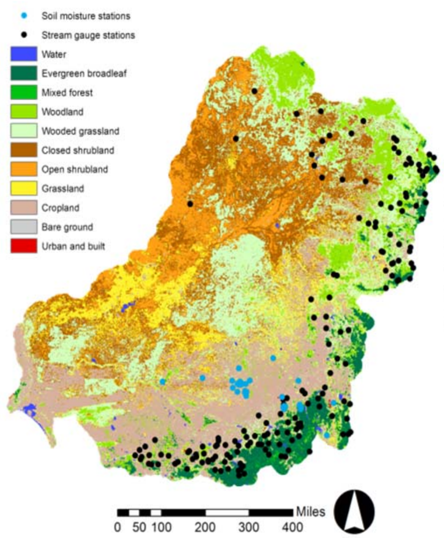
J. Bolten

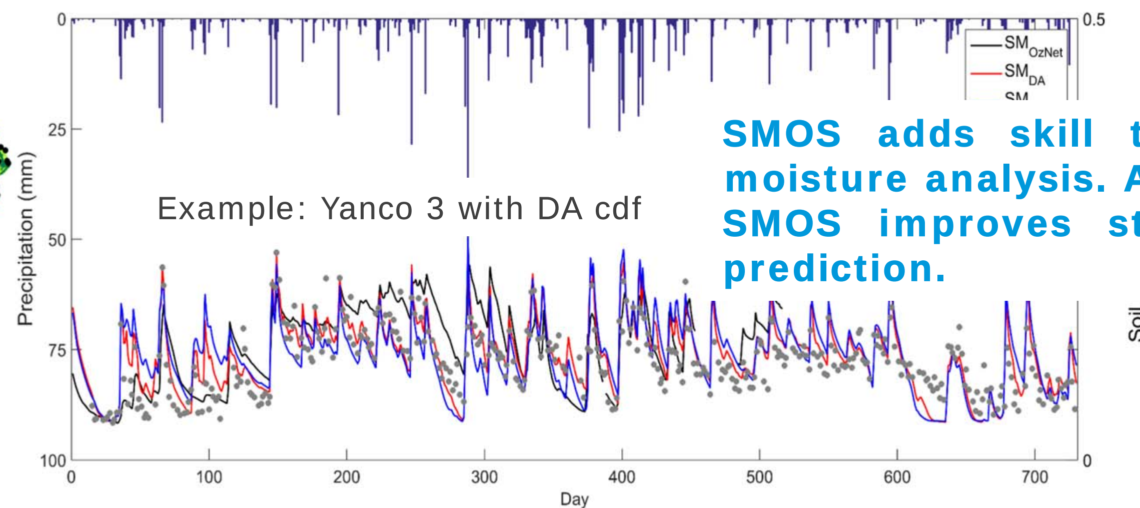


STREAM FLOW PREDICTION
Assimilating SMOS Soil Moisture

smos+hydrology support to science element | esa

Assimilate SMOS soil moisture into a the variable infiltration capacity (VIC) model to predict stream flow





SMOS adds skill to the soil moisture analysis. Assimilating SMOS improves stream flow prediction.

All stations:

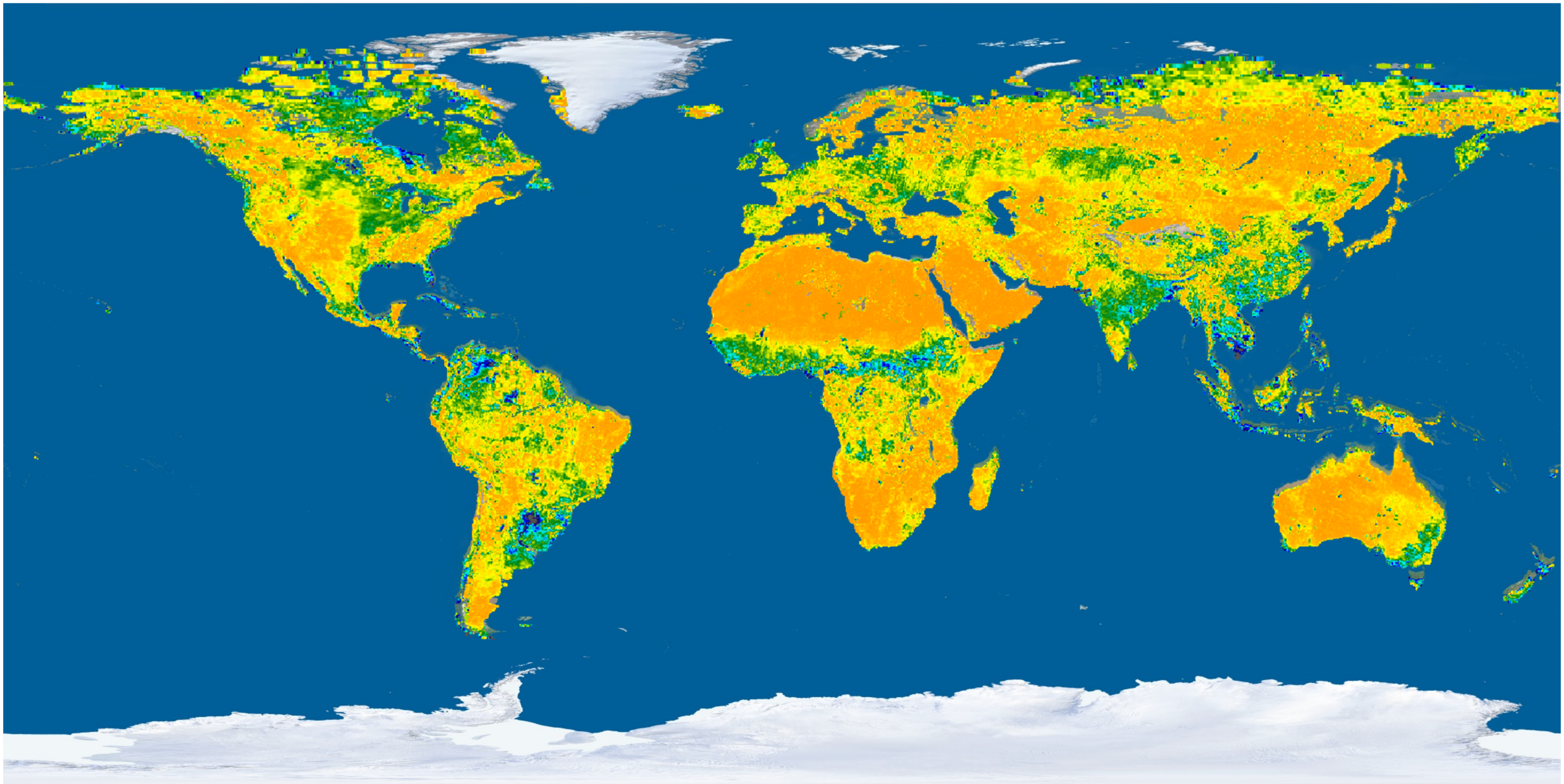
SM record	**RMSE *cdf* (m³/m³)**	**R *cdf* (-)**
VIC OL	0.058	0.549
VIC DA *mean*	0.045	0.713
VIC DA *var*	0.048	0.677
VIC DA *cdf*	0.048	0.686

From: Lievens et al. (2016) Assimilation of SMOS soil moisture and brightness temperature products into a land surface model, RSE Special issue on SMOS

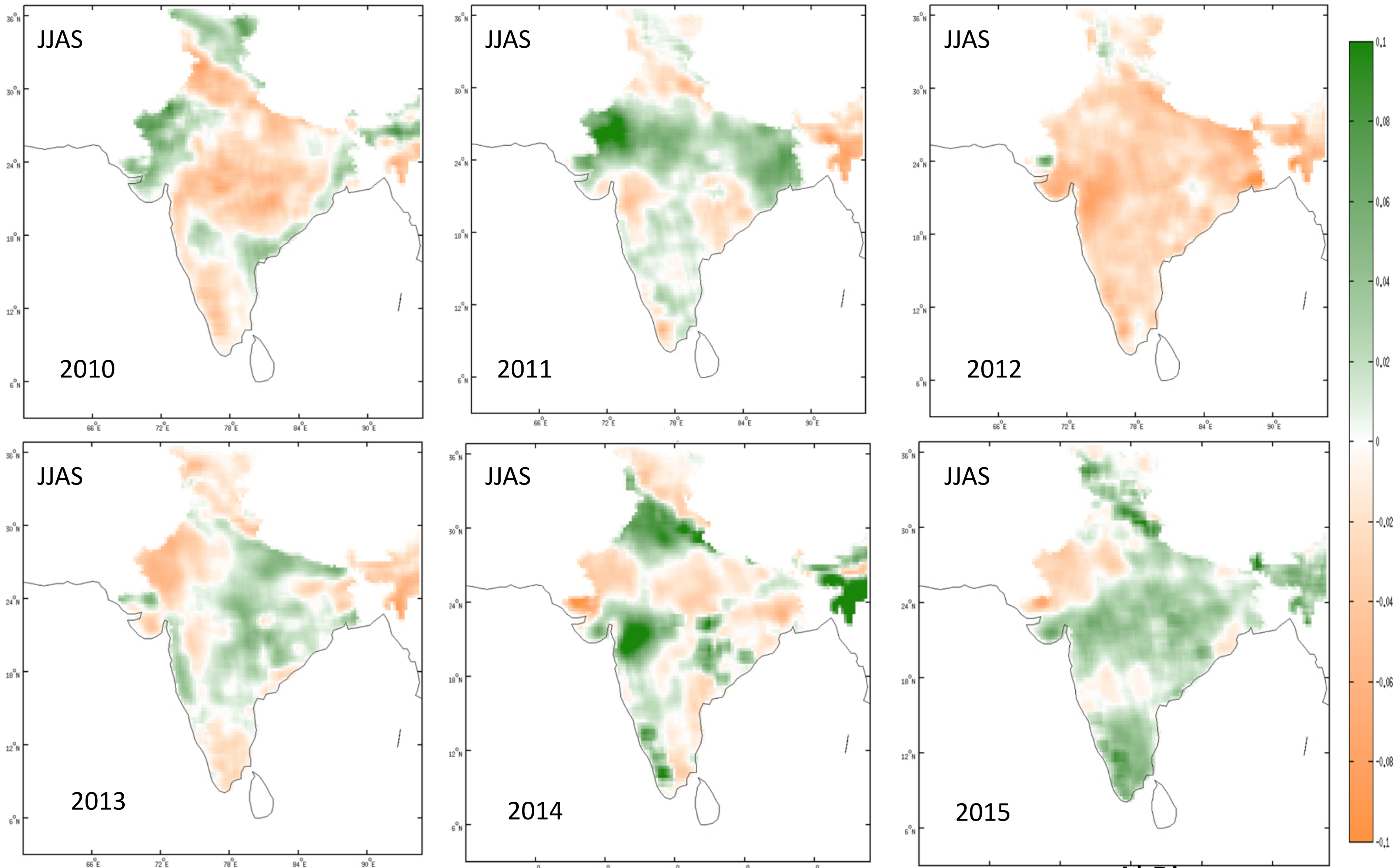
<u>Now</u>: Working with WMO FFG System to assess skill of assimilating SMOS data – first assessment positive for lower FFG values. Further work planned.

Root zone soil moisture in 2016

Feb. / May / Aug. / Nov/ 2016



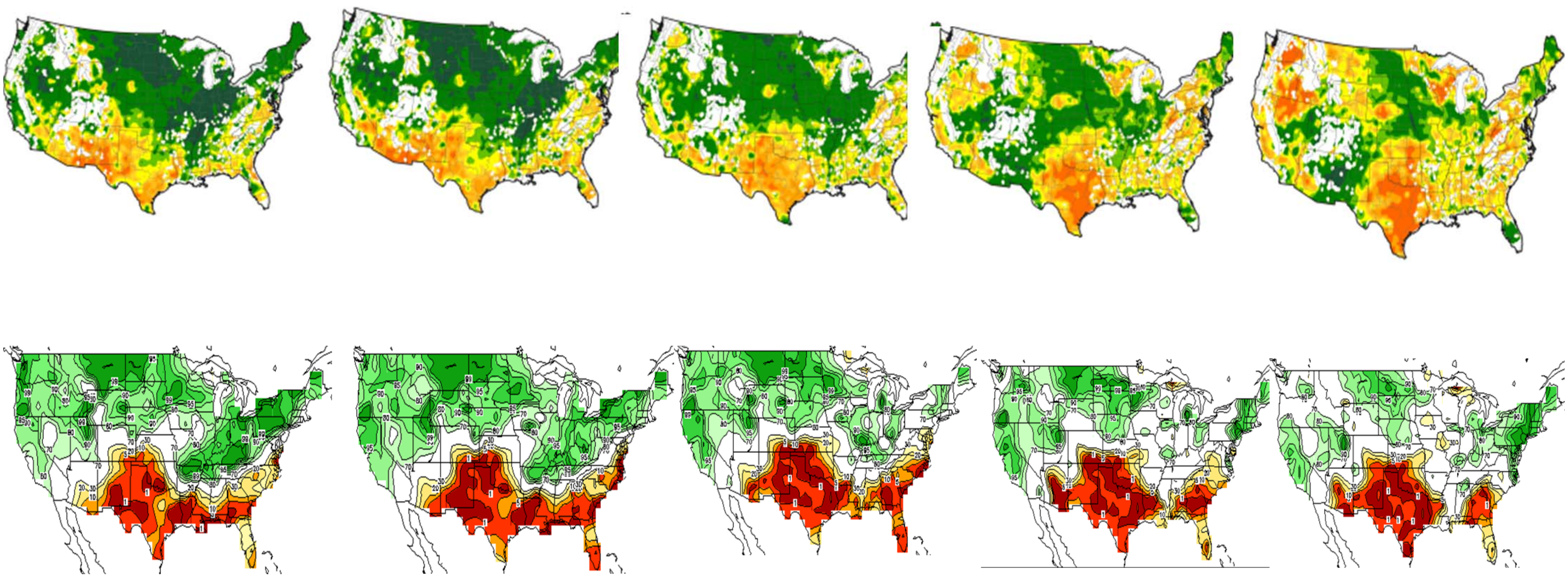
Root zone soil moisture anomaly: India



Al Bitar

RZ soil moisture vs NOAA NCEP Bucket model

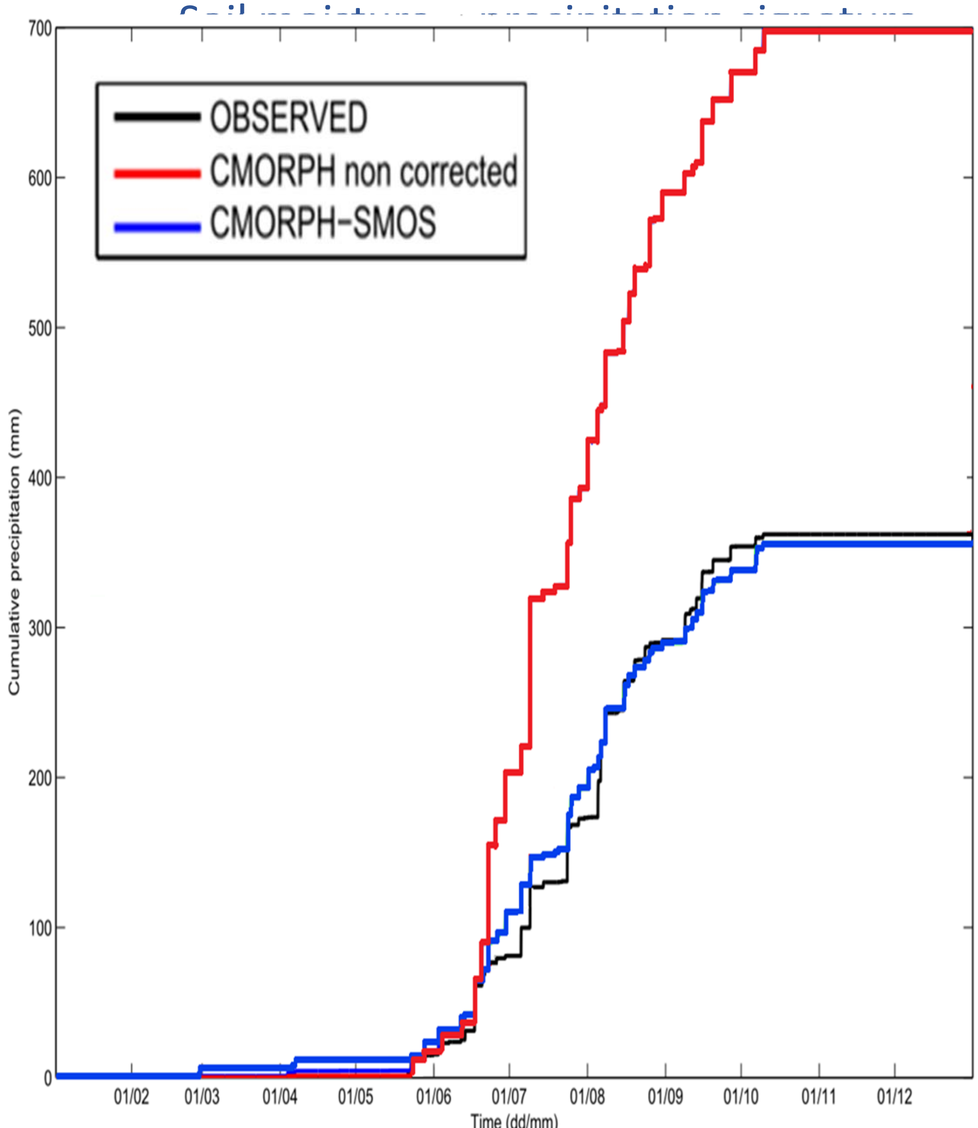
May 2011 | June 2011 | July 2011 | August2011 | September 2011



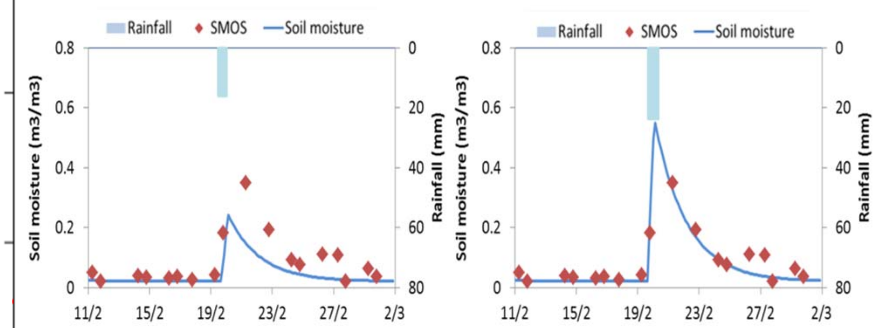
Al Bitar

Rainfall estimates using SMOS in Africa

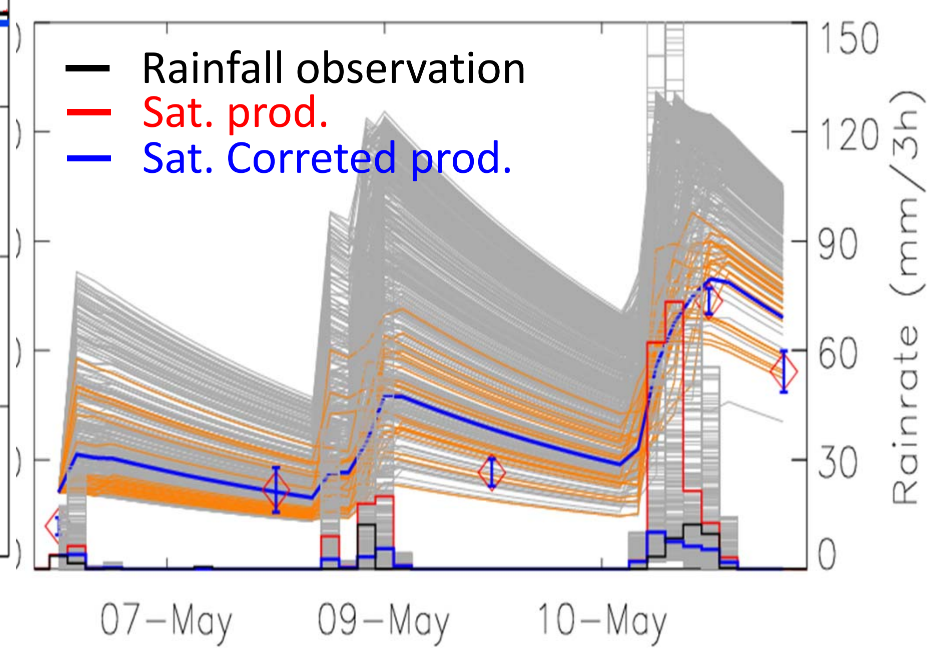
Cumulative rainfall (Niger – 2011)



Optimisation of the rainfall amount at the event scale



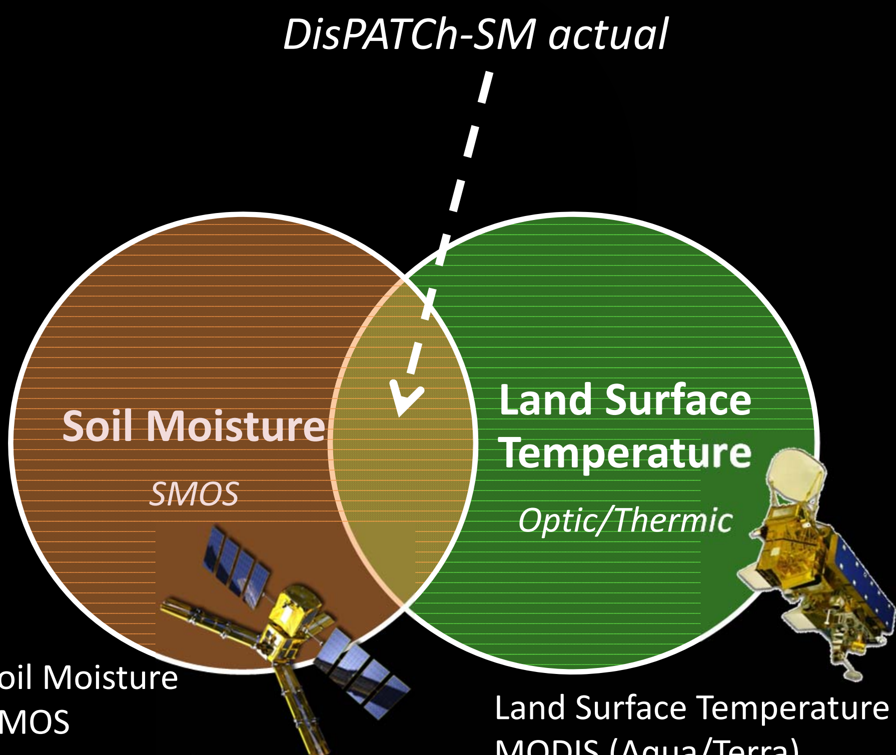
Particle filter assimilation scheme



T. Pellarin

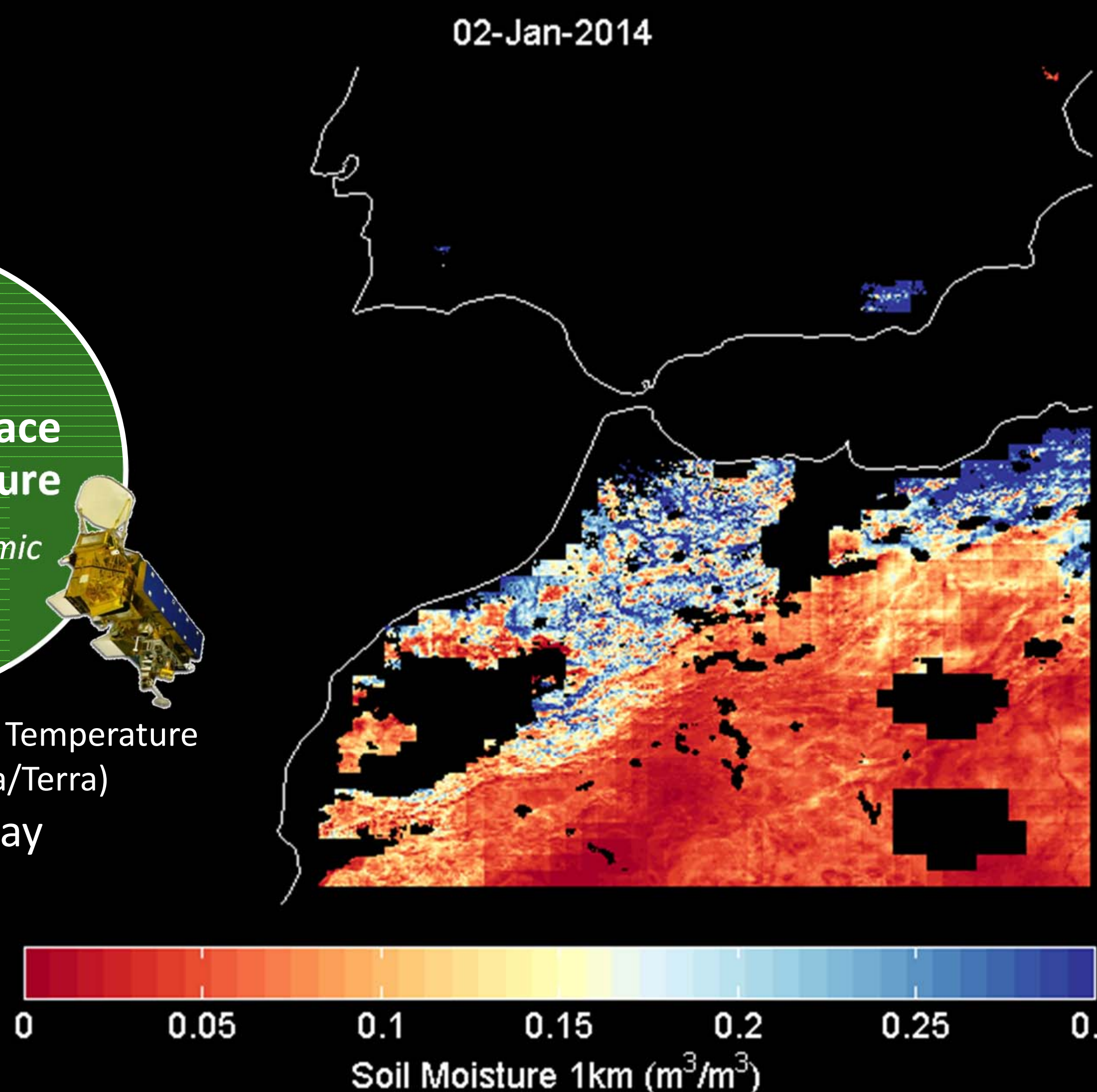
J. Malbeteau

Soil Moisture 1 km Morocco



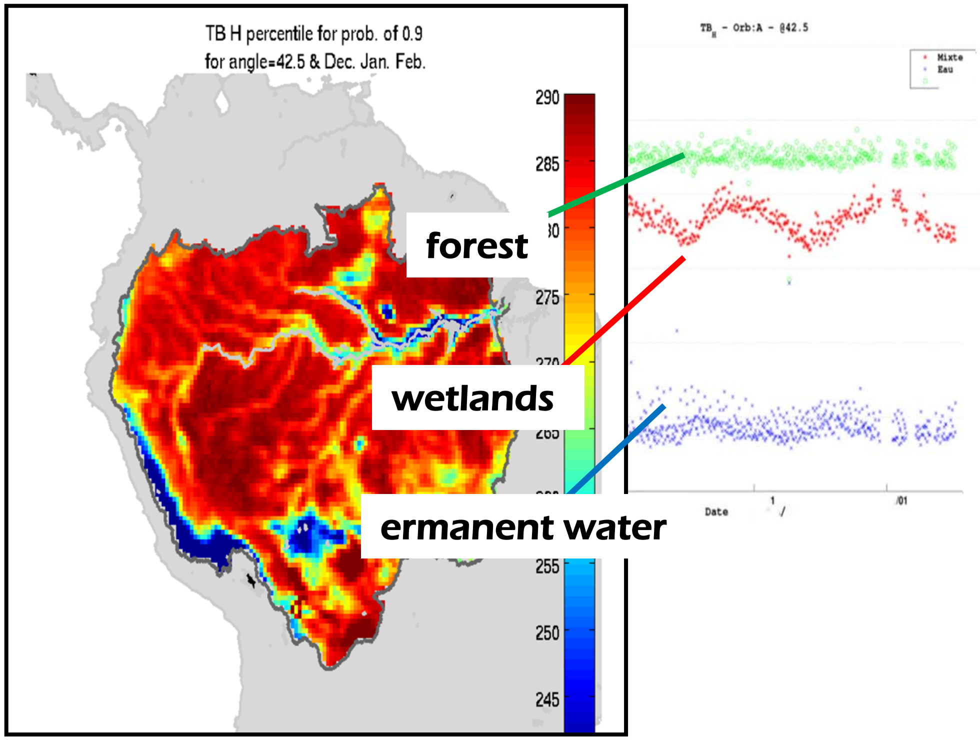
Soil Moisture
SMOS
40 km / 3 days

Land Surface Temperature
MODIS (Aqua/Terra)
1 km / 1 day

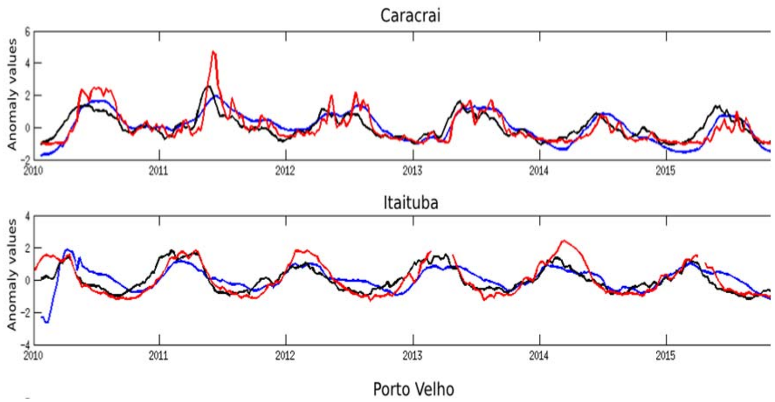


SWAF – SMOS water fraction

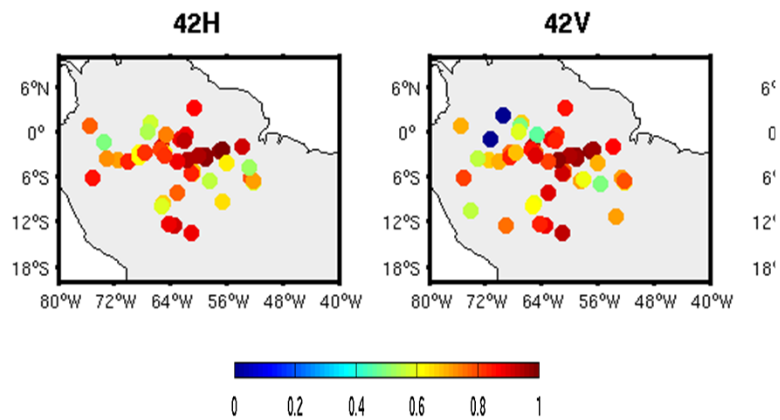
Principle: SMOS brightness temperature measurements differ over forest, wetlands and permanent waters



Courtesy of: Al Bitar et al. (CESBIO)

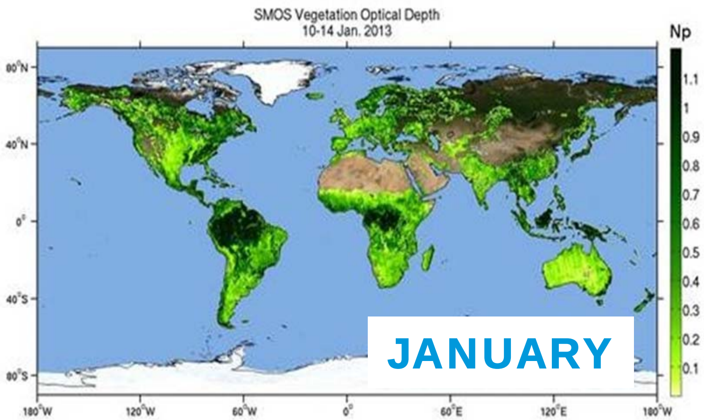


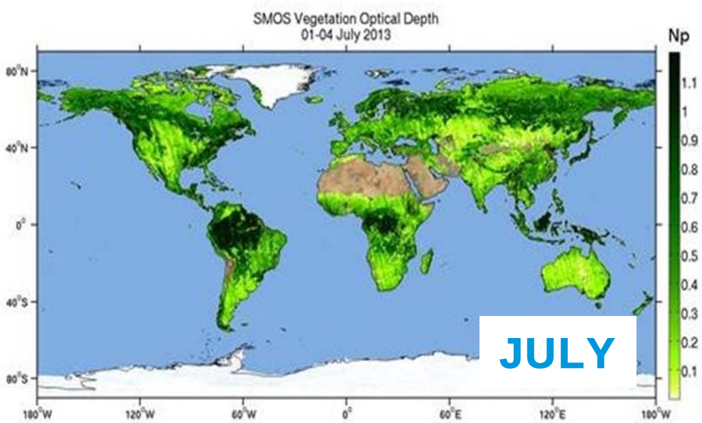
Application: SWAF is directly linked to river discharge.



Successful validation/ high correlation of SWAF with altimetry based water height from Jason-2.

VEGETATION OPTICAL DEPTH

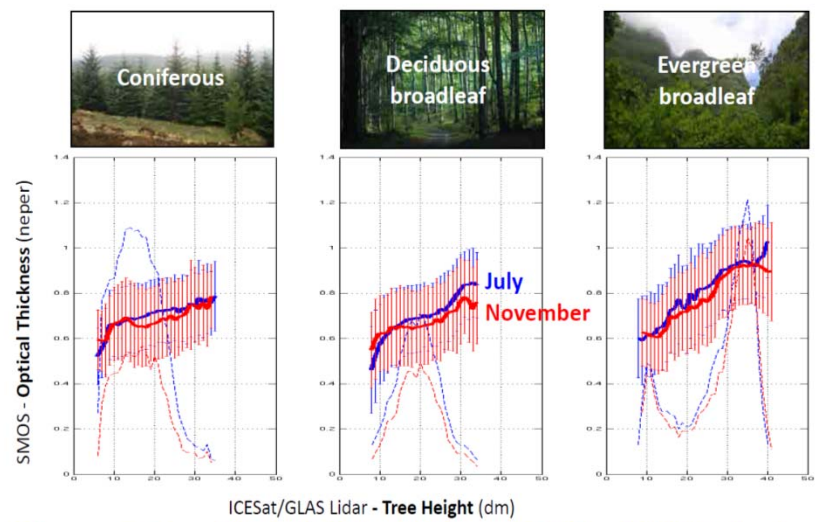




Monthly vegetation optical depth derived from SMOS data for January (top) and July (bottom) 2013. Seasonal differences in vegetation are well visible. Credit: CESBIO, ESA.

- SMOS 'sees' the vegetation layer as a homogeneous cloud of vegetation elements, air, and water (in and on the vegetation)
- **Vegetation Optical Depth (VOD) is a measure of the transmissivity of the vegetation layer** = transparency of the layer for electromagnetic radiation at a given frequency
- **Potential applications:** Agriculture: plant available water, stress/drought monitoring; Terrestrial biosphere and carbon modelling; Climate studies; Landscape ecology

Optical thickness over forests



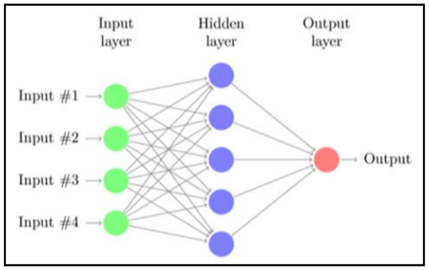
Rahmoune, R., Ferrazzoli, P., Singh, Y., Kerr, Y., Richaume, P., Al Bitar, A. SMOS Retrieval Results Over Forests: Comparisons With Independent Measurements. J-STARS ,2014

52

Comparing VOD and tree height (LIDAR): "validation" and improving representation of forested areas in L2 processor

New vegetation products: biomass

SMOS averages (Tb's, SM, tau)



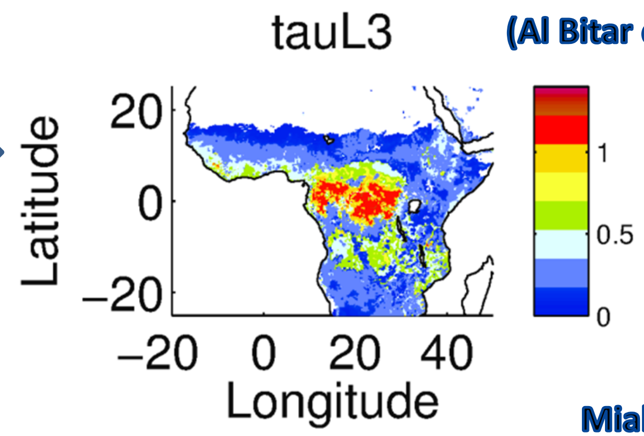
NN Biomass

SMOS biomass Maps from 2010 to 2016

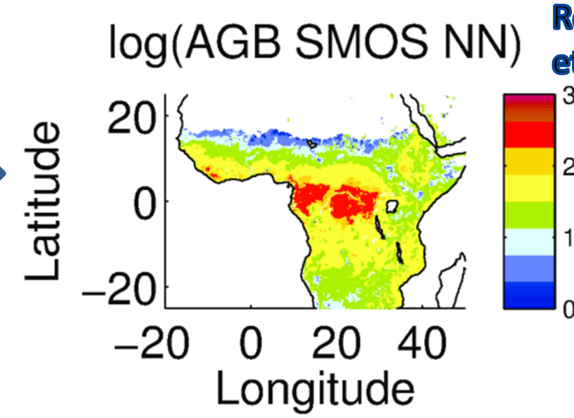
Training in 2010

Trained on Palsar Biomass from CESBIO Biomass team (Bouvet et al. 2017)

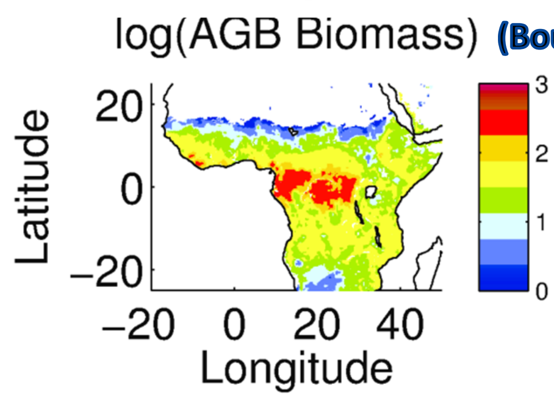
(Al Bitar et al. 2017)



Mialon, Rodriguez-Fernandez, et al. (in prep)

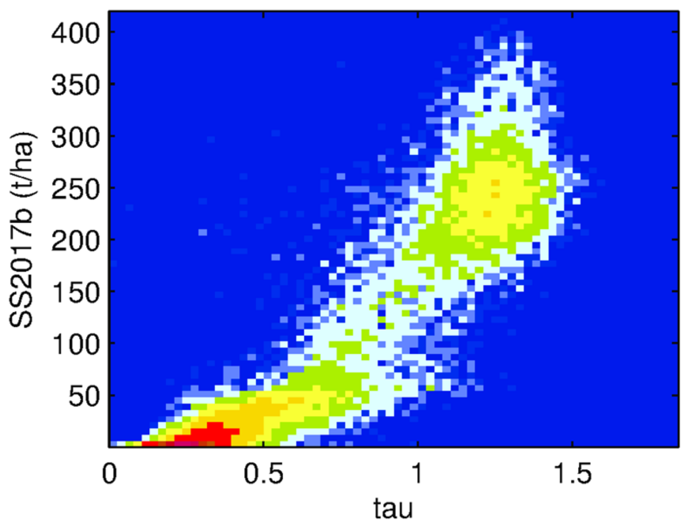


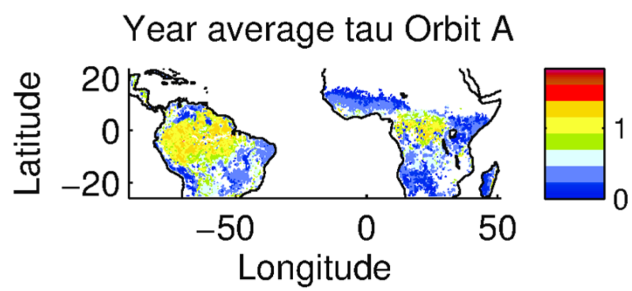
(Bouvet et al. 2017)

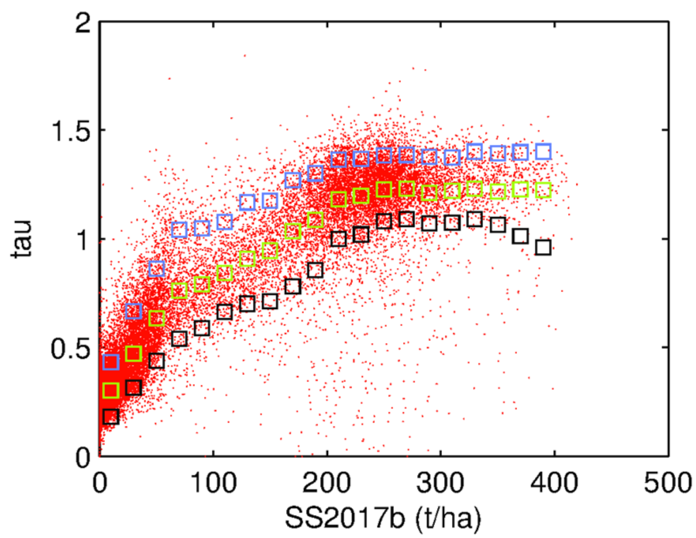


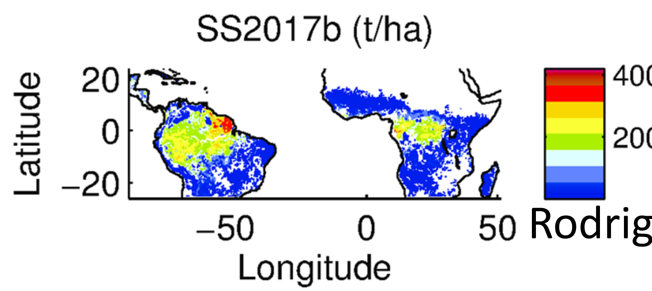
Rodriguez et al.

Biomass with L Band radiometry







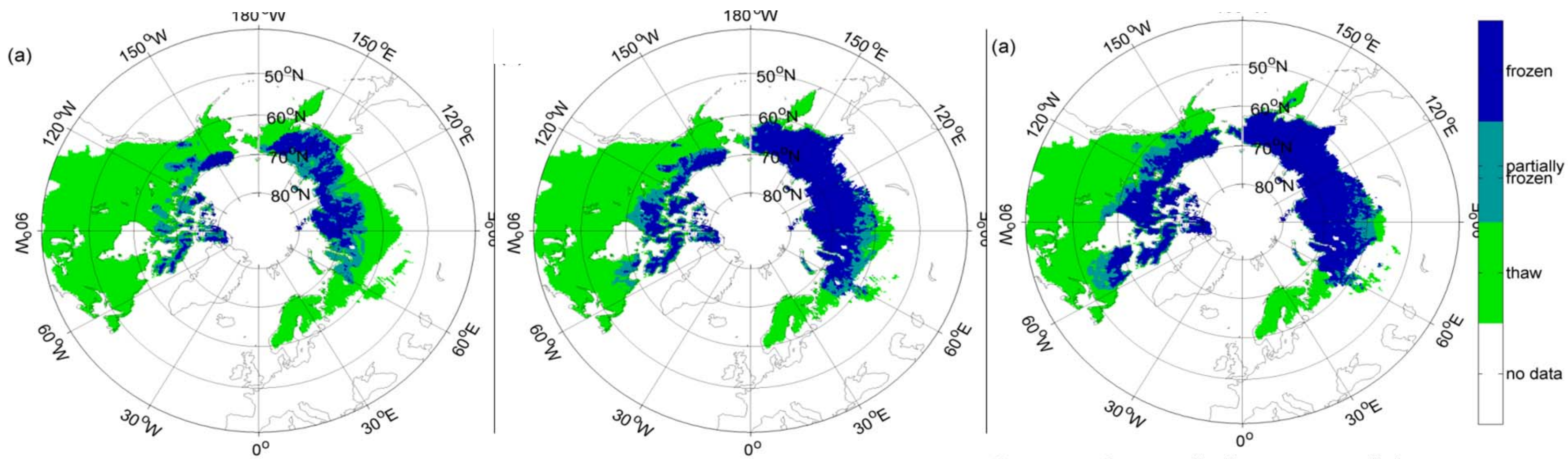


Rodriguez et al.

Nemesio Rodriguez Fernandez

FREEZE AND THAW

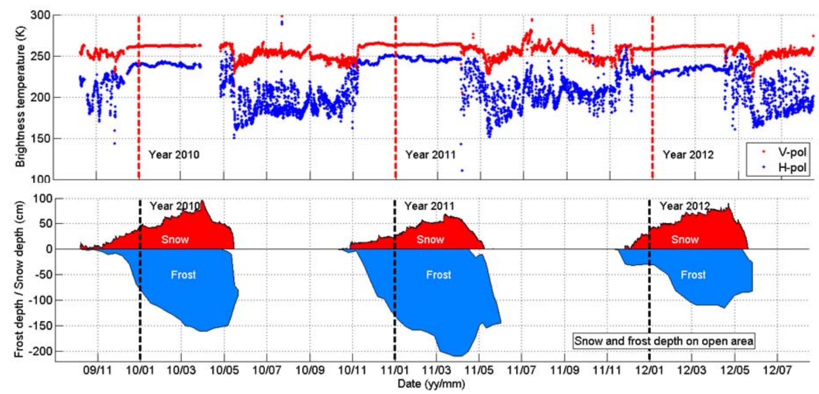
10 Oct 2015 **20 Oct 2015** **30 Oct 2015**



© FMI (Rautiainen et al.)

Product will become systematically available form mid-2017 from FMI distributed by ESA and CATDS

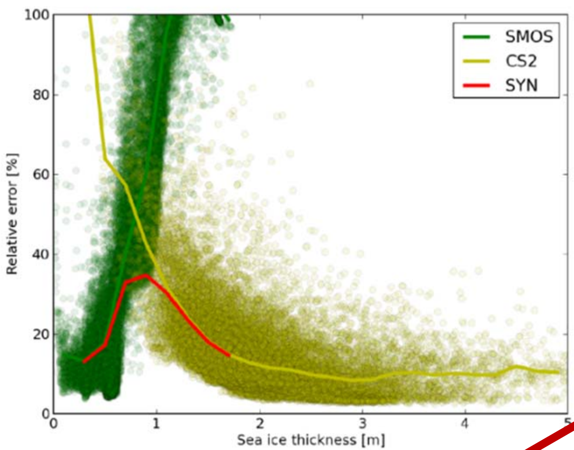
- Retrieval based on empirical change detection algorithm using 3 years of ground based L-Band observations and in-situ measurements (e.g. soil frost tube observations)
- Product now available!
  - Daily product
  - Coverage: Northern Hemisphere EASE grid projection
  - Three soil state categories "frozen", "partially frozen", "thaw" and one "no data" category
  - Currently available 6 years: 2010-2015
  - Will be accompanied with quality estimation flag (pixel-wise)
  - Work continues to make the product operational(updates with 1-2 days latency)



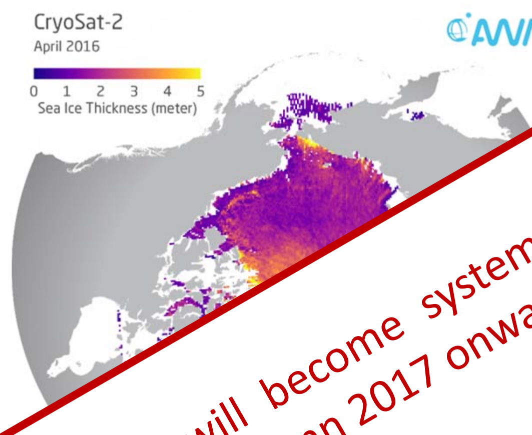
Rautiainen, K., Parkkinen, T., Lemmetyinen, J., Schwank, M., Wiesmann, A., Ikonen. J., Derksen, C., Davydov, S., Davydova, A., Boike, J., Langer, M., Drusch, M., Pulliainen, J., (2016) SMOS prototype algorithm for detecting autumn soil freezing, Remote Sensing of Environment

SMOS + CryoSAt-2 SEA ICE THICKNESS

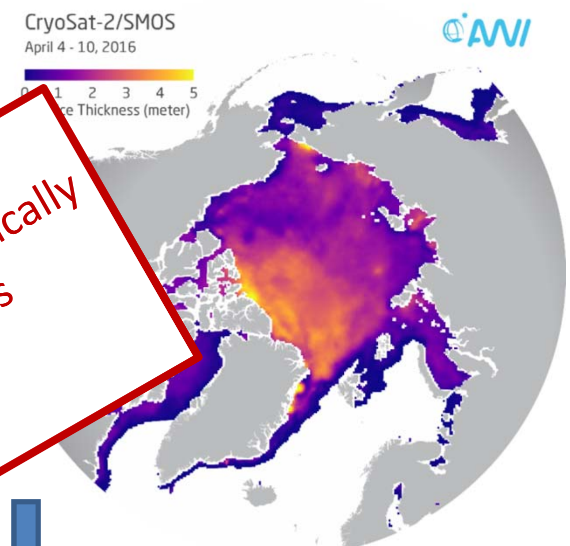
Synergy ice product based on SMOS and CryoSat data



One month of CryoSat-2



One week of SMOS + CryoSat-2

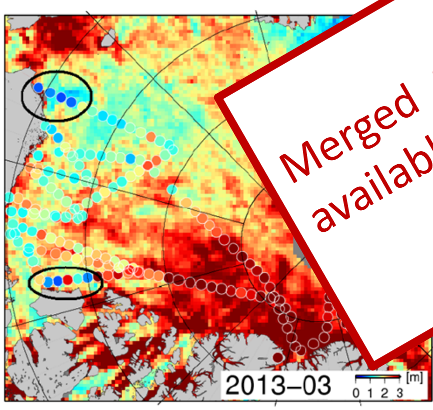


Ricker and Hendricks, AWI

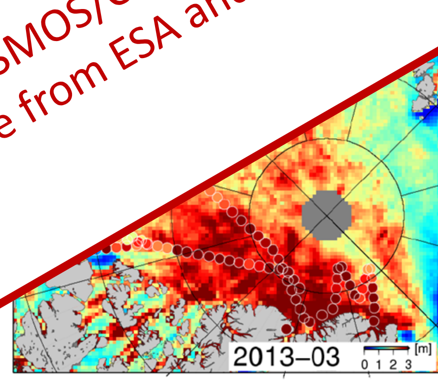
Merged SMOS/Cryosat Product will become systematically available from ESA and AWI from autumn 2017 onwards

- ❑ Combining both sensors' skill
- ❑ Improving spatial and temporal coverage for thin sea ice as well as product structure and content
- ❑ To be released soon
- ❑ Algorithm validation using IceBridge 2013 campaign data

Validation with NASA IceBrid



CryoSat-2 only



Synergy (weighted average) of CryoSat-2 and SMOS

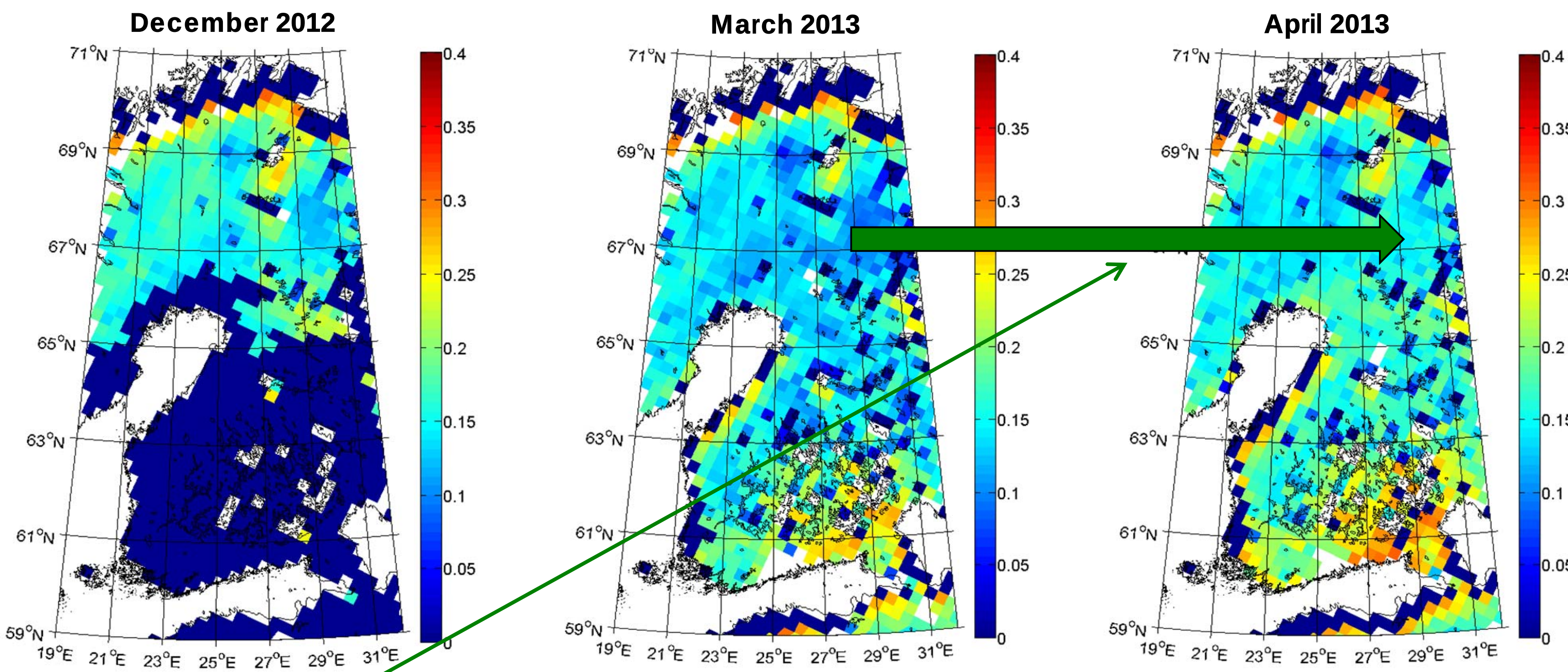
AWI-retracked Cryosat-2 thickness courtesy of Robert Ricker; Preliminary results.

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Snow density

Demonstration Retrievals (ρ_S, ε_G) using SMOS Data:

→ **Snow density maps over Finland during Winter 12/13 based on weekly averaged SMOS L3 $T_B^p(\theta)$ at θ = 30° - 60°, p = H & V.**



Findings:

- Novel retrieval option works technically.
- "Densification" of the lowest snow layer from March to April 2013.

Schwank, M., Lemmetyinen, J.

What L band brings us

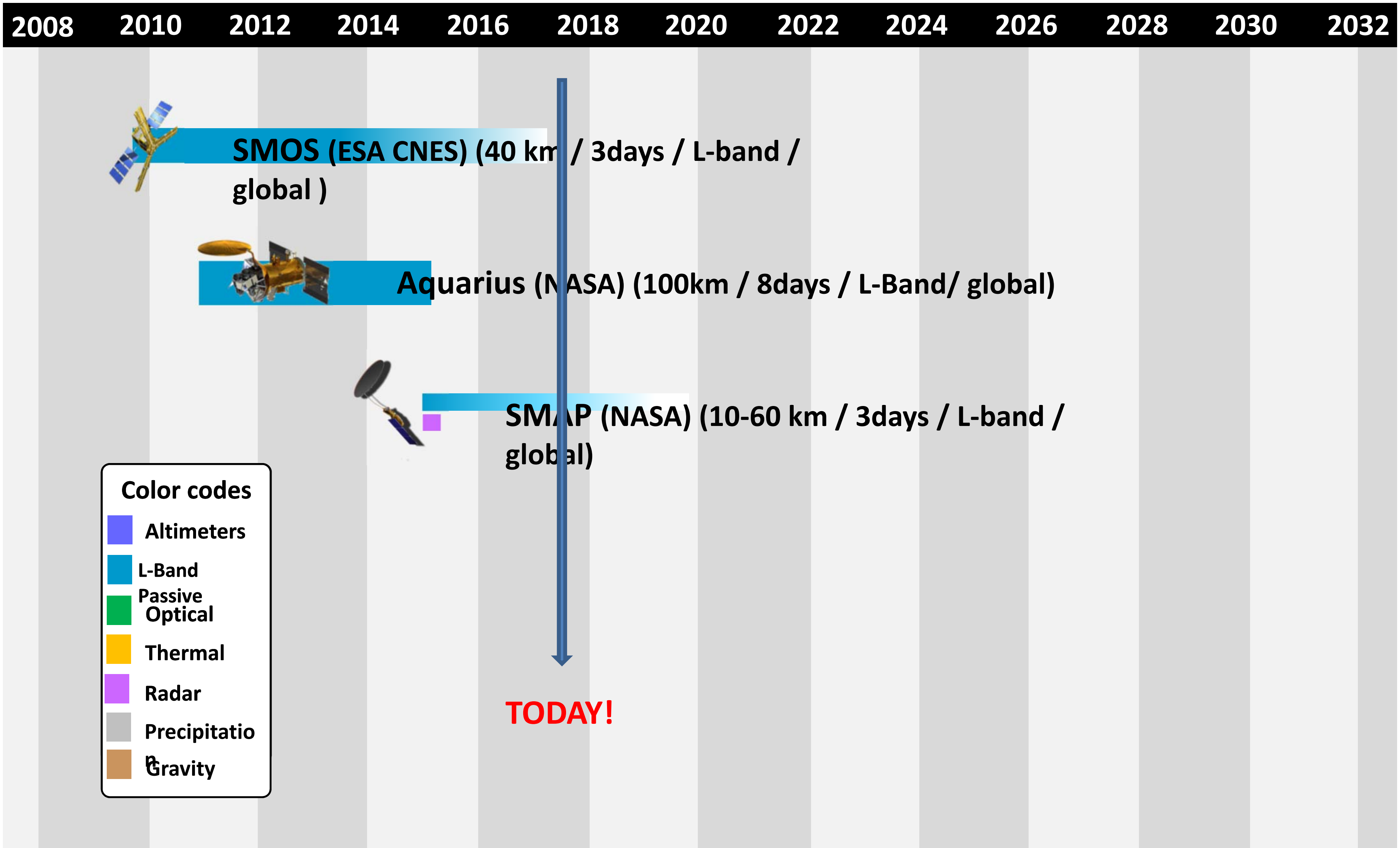
- Net gain over active or higher frequency data sets for soil moisture and hydrology hence agriculture/NWP
- Complementary to optical/thermal and radar
  - Which either see the “envelope” or the structure
- AND
  - Little sensitivity to cloud/ rain →all weather all time (~twice every 2 days in Europe, daily with two missions)
  - Reduced sensitivity to vegetation cover
  - Appreciable penetration depth
  - → anticipate!
- Caveats
  - Spatial resolution
    - But temporal coverage
    - Solutions exist

What's next

- SMOS-SMAP product
  - Daily coverage
  - Uses advantages of both (One algo with SMOS-IC)
- VOD product
- Long term time series (15 years currently)

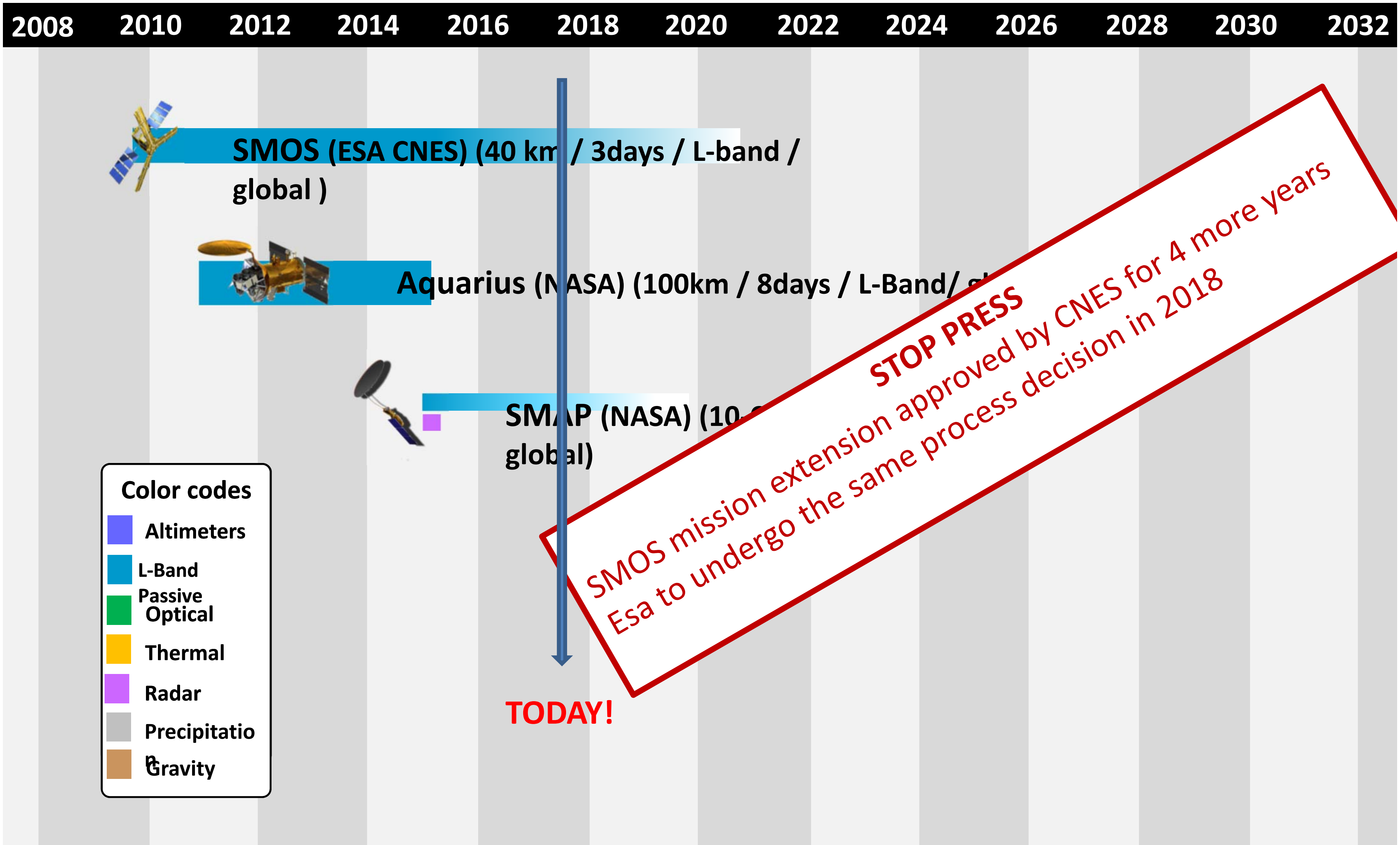
Kerr and Al Bitar

L-Band radiometry missions



Kerr and Al Bitar

L-Band radiometry missions



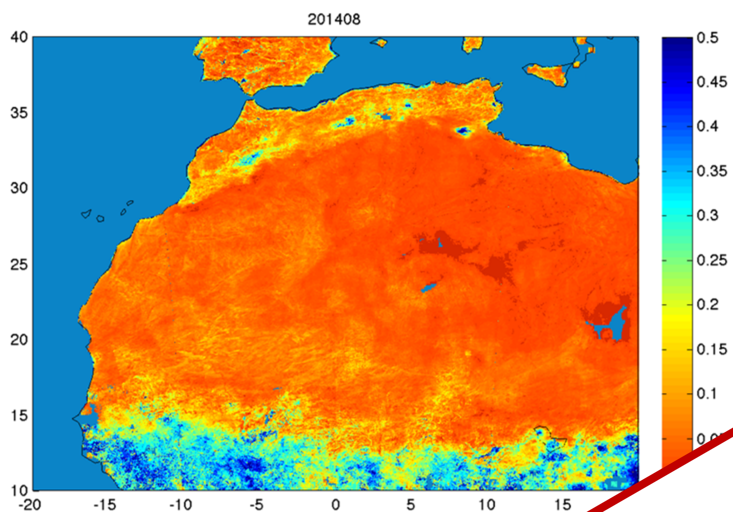
What’s next

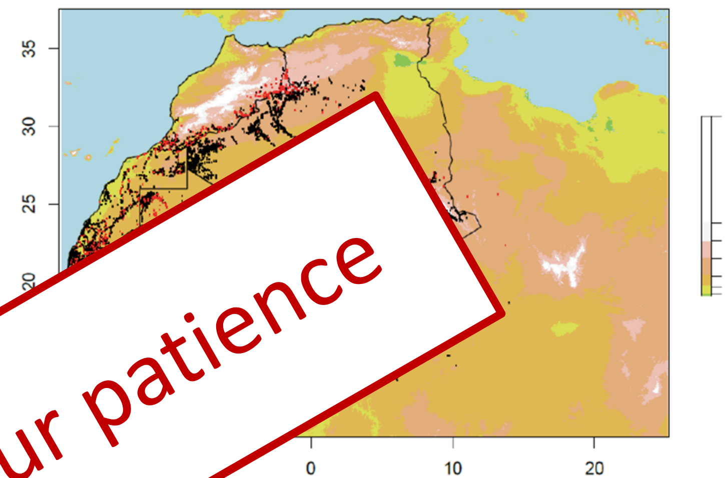
- SMOS-SMAP product
  - Daily coverage
  - Uses advantages of both (One algo with SMOS-IC)
- VOD product
- Long term time series (15 years currently)
- SMOS-HR concept
  - 10 m structure
  - ~ 10 km intrinsic spatial resolution (3dB)
  - Possibility to disaggregate to 100-500m
    - Optical + active
  - Overall feasibility analysis for phase 0 before end of 2017
  - User’s requirements underway (science and application)
- Targets
  - EU Copernicus expansion → **EU CALENDAR!!**
  - ISRO CNES bilateral
  - Cnes NASA partnership?

Summary

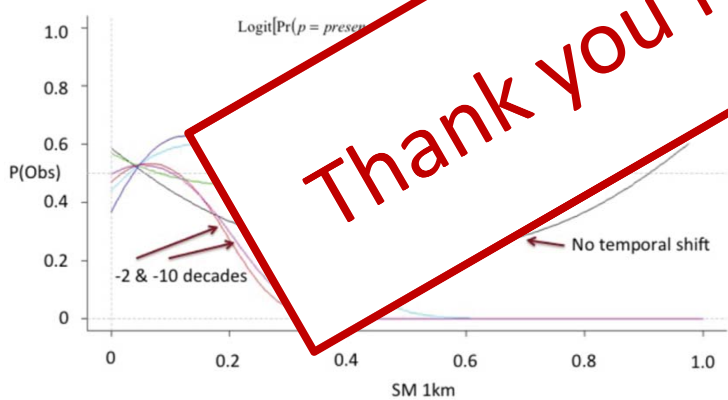
- Need for soil moisture (and sea surface salinity and thin sea ice and etc…) measurements continuity
- Why passive L band?
  - Because of its characteristics and inherent qualities
  - The most appropriate tool as shown by all the products stemming from it
  - Temporal stability and robustness
- L band radiometry → proof of concept demonstrated
  - **Uniqueness** of the measurements hence
    - Many science outstanding results
    - A very large number of operational or pre operational demonstration products
    - Not a strange parcel !
- BUT …
  - No follow on mission currently → **Data gap**
  - **High risk of loosing a very useful tool (and frequency allocation)**
  - **Need to act now!**

SMELLS 1 km v2





Thank you for your patience



- …il moisture downscaled at 1km (…SPATCh) produced over the entire region (2010 -2015)
- SMELLS 1km can explain Desert Locust (DL) presence
- Current approaches rely on NDVI at 3km
- Introduction of SM increases resolution (1km)

SM precedes vegetation by 2 months ->
high impact on DL management

M.J. Escorihuela

SPARES

Unicity of passive L band measurements

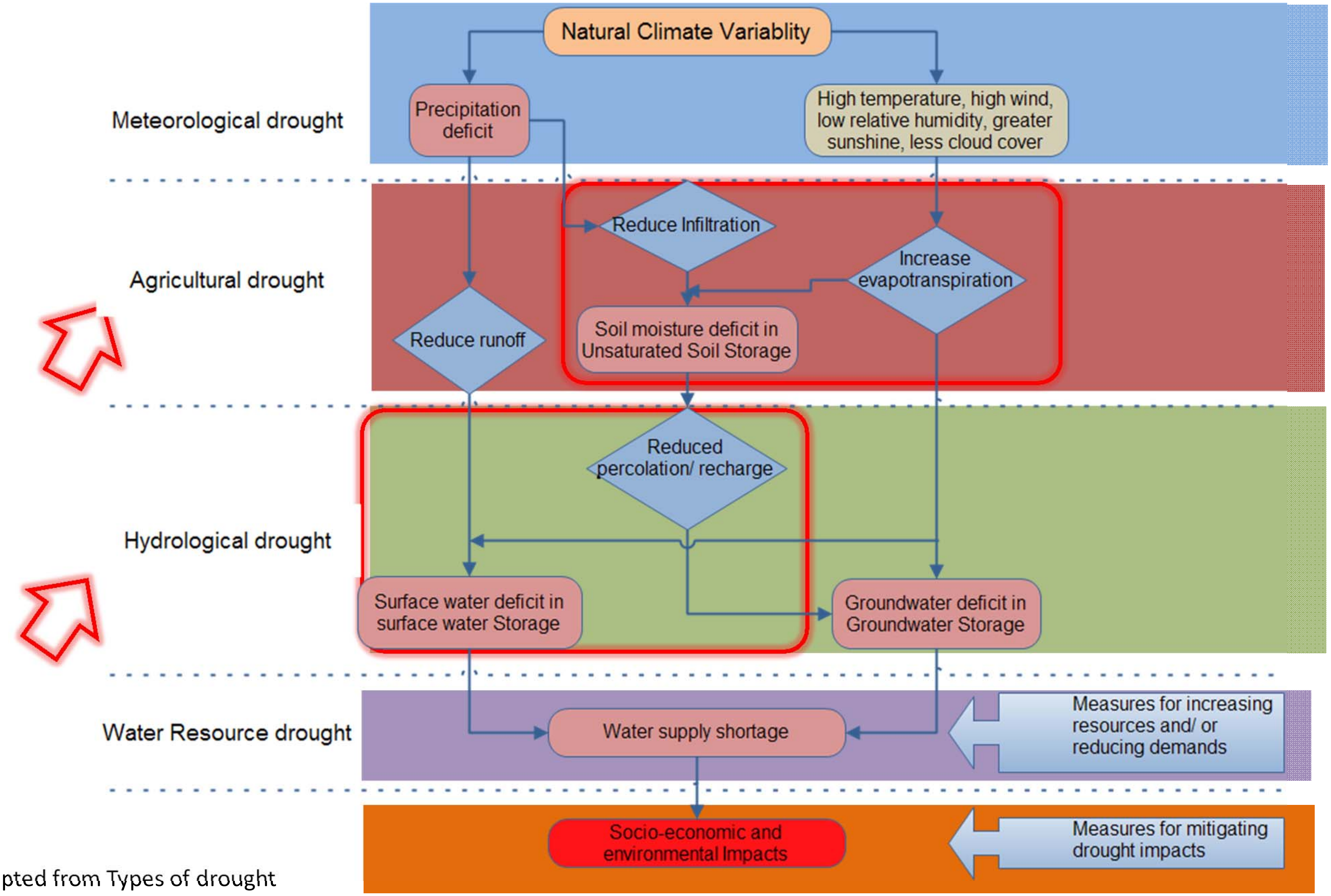
PROS

- Passive microwaves at low frequency
  - Reduced sensitivity to atmosphere and sun irradiance (all weather)
  - reduced sensitivity to structure
    - Vegetation canopy
    - Surface roughness
- L band measurements (passive: Radiometry different from RADAR)
  - Reduced sensitivity to vegetation canopy
  - Good penetration depth
  - Sensitivity to sea salinity
  - High sensitivity to soil moisture
- Direct measurements of Soil moisture and Sea Surface salinity (no proxy, no scaling, …) hence usable in applications

CONS

- Spatial resolution (antenna diameter)
  - Meaning different options (i.e., SMOS, Aquarius, SMAP)
  - and different price tags (€ 315 M, $400 M - instrument, $ 915 M)
  - Radio frequency interferences
    - …See ITU actions and SMAP approach

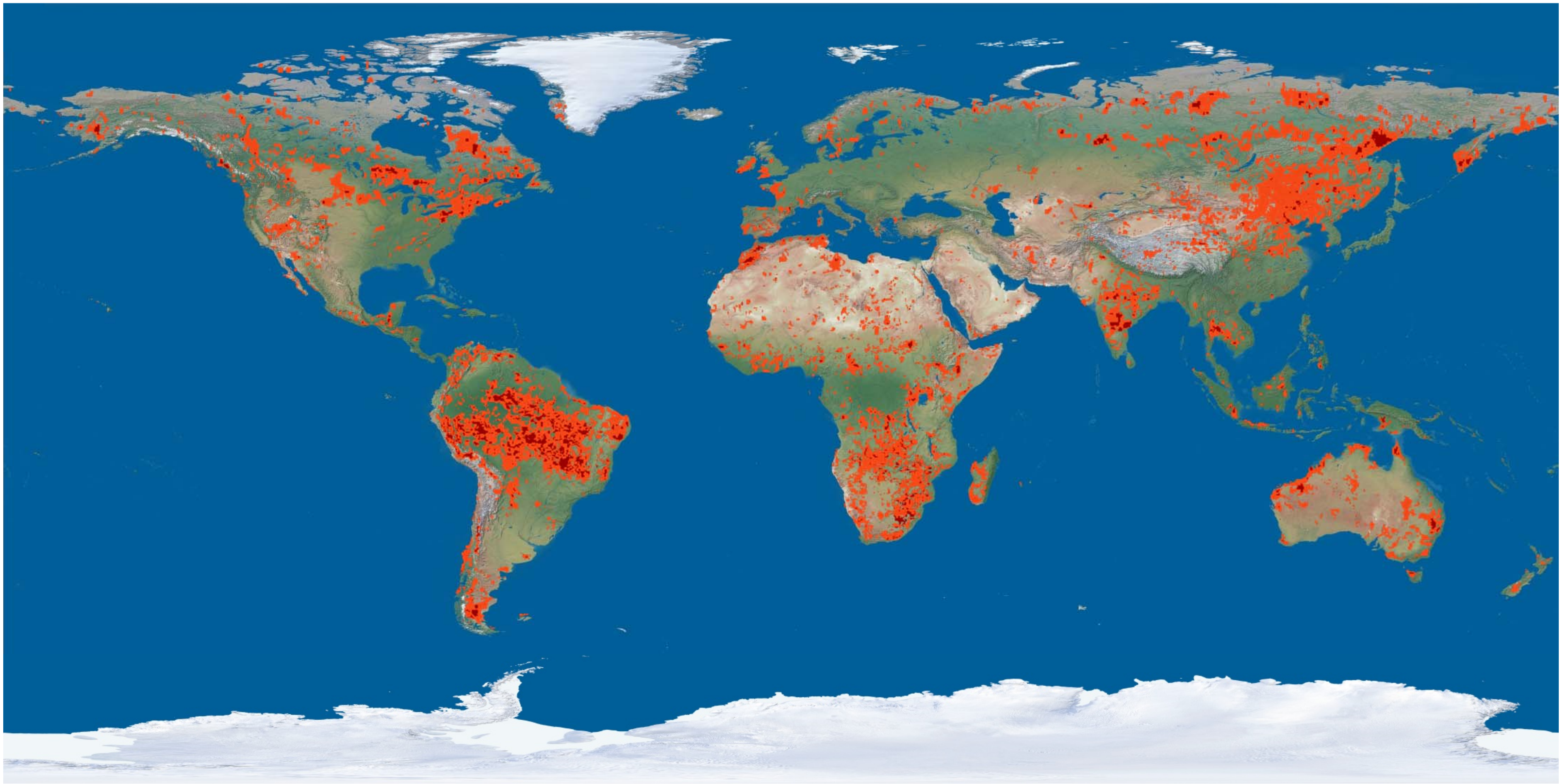
Types of drought



Adapted from Types of drought

Source: Cullmann Adopted from National Drought Mitigation Centre, and G. Rossi, B. Bonaccorso, A. Cancelliere, (2003) Droughts from Root zone soil moisture anomalies 2016

Feb. / May / Aug. / Nov/ 2016



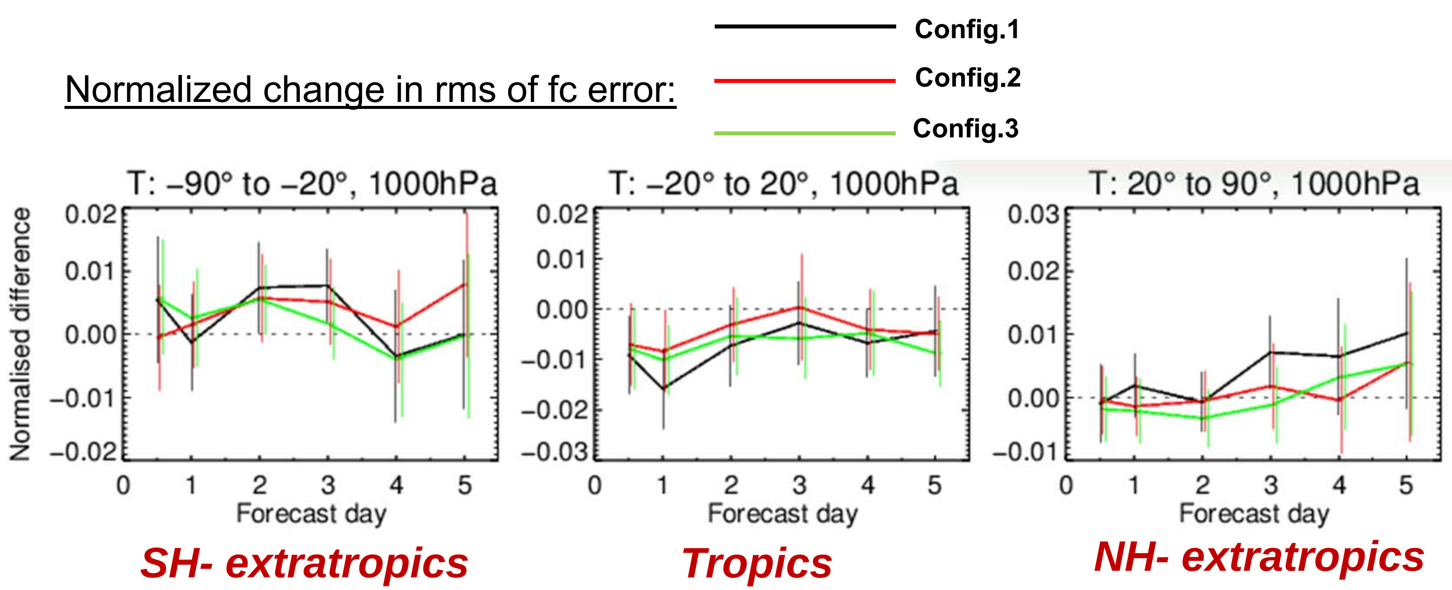
What is looming a world food crises because of prolonged drought conditions, that can be driven from socio-climatique situations.

Summary

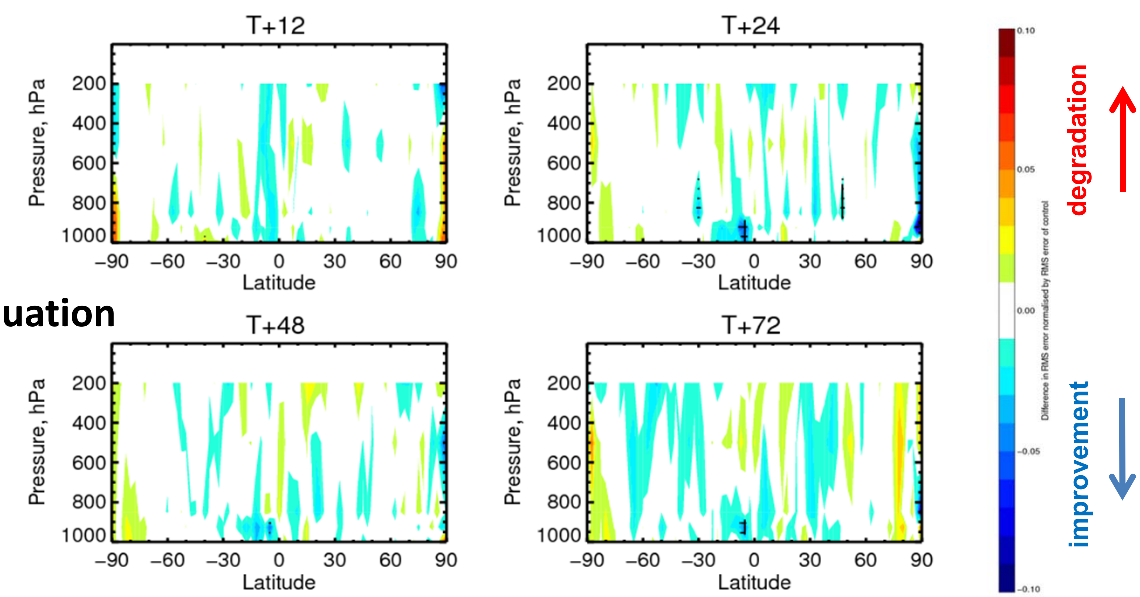
- A challenging project
- Initiated Almost 30 years ago
- A huge success
  - Publications
  - New science
  - Operational applications
- Issues
  - RFI
  - Continuity
- **CRUCIAL ISSUE**
  - **Data continuity as no L band mission is currently scheduled in spite of operational and science applications demonstrated over land, oceans, coastal areas, cryosphere and meteorology**
- → to be analysed as multi mission in Copernicus rounds

- A lots of very sincere thanks to the operation's teams, and dedicated contributors worldwide
  - **Our successes only exist thanks to them!**

SMOS data assimilation in the IFS



Near Real time available



Based on short experiments
Longer experiment under evaluation

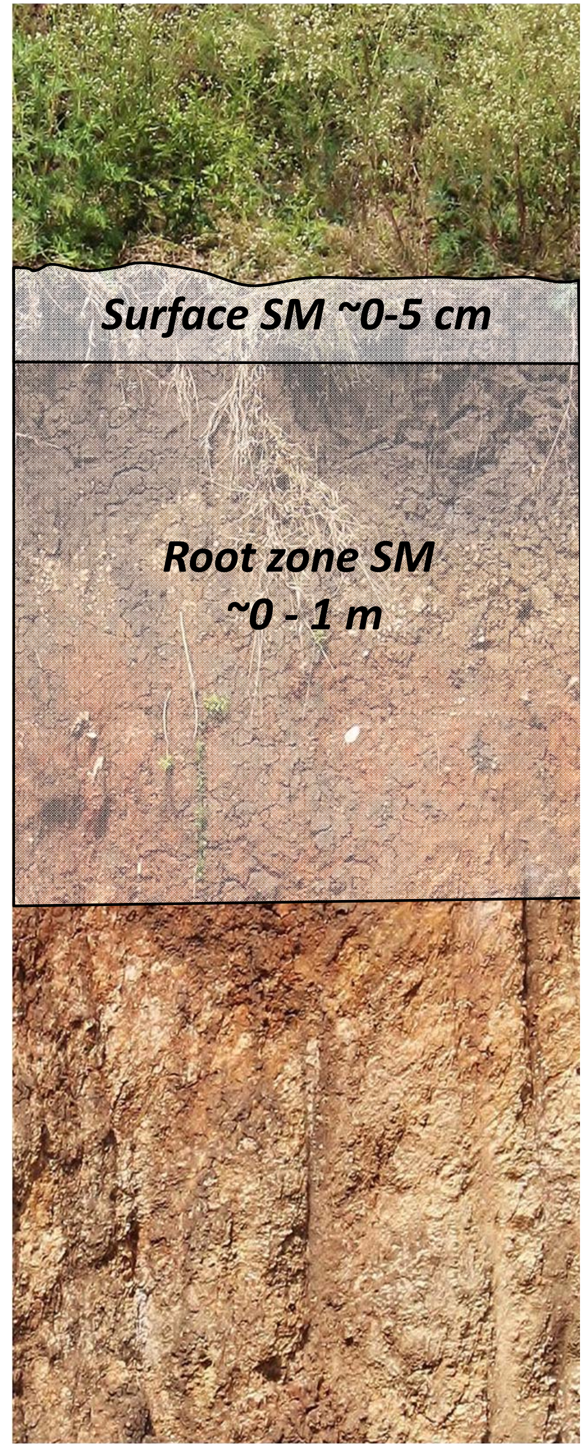
Root zone soil moisture

Root zone soil moisture is a very useful information to access agricultural drought in an **early warning system**

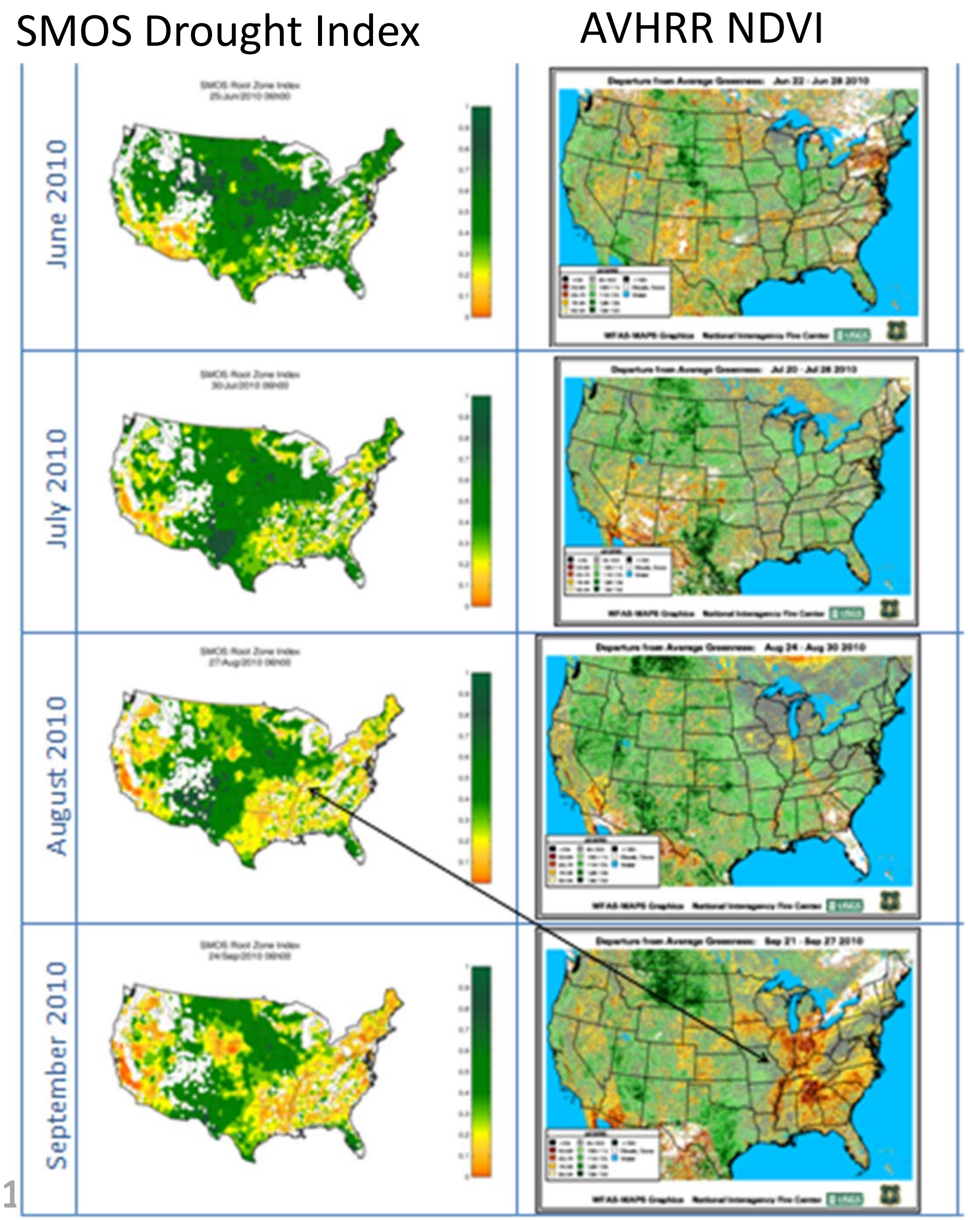
SMOS measures surface soil moisture, root zone soil moisture needs to be modeled

At CESBIO **SMOS surface soil moisture** and MODIS LAI are assimilated into a double bucket model to compute **root zone soil moisture**.
(Al Bitar et al. 2013, Kerr et al. 2016)

Al Bitar



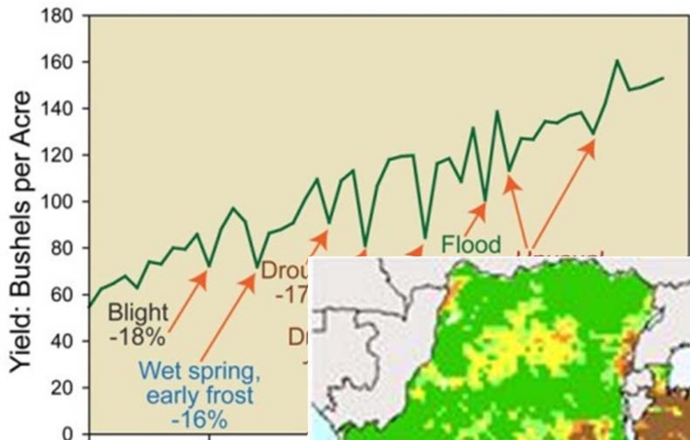
Vegetation and Root zone soil moisture



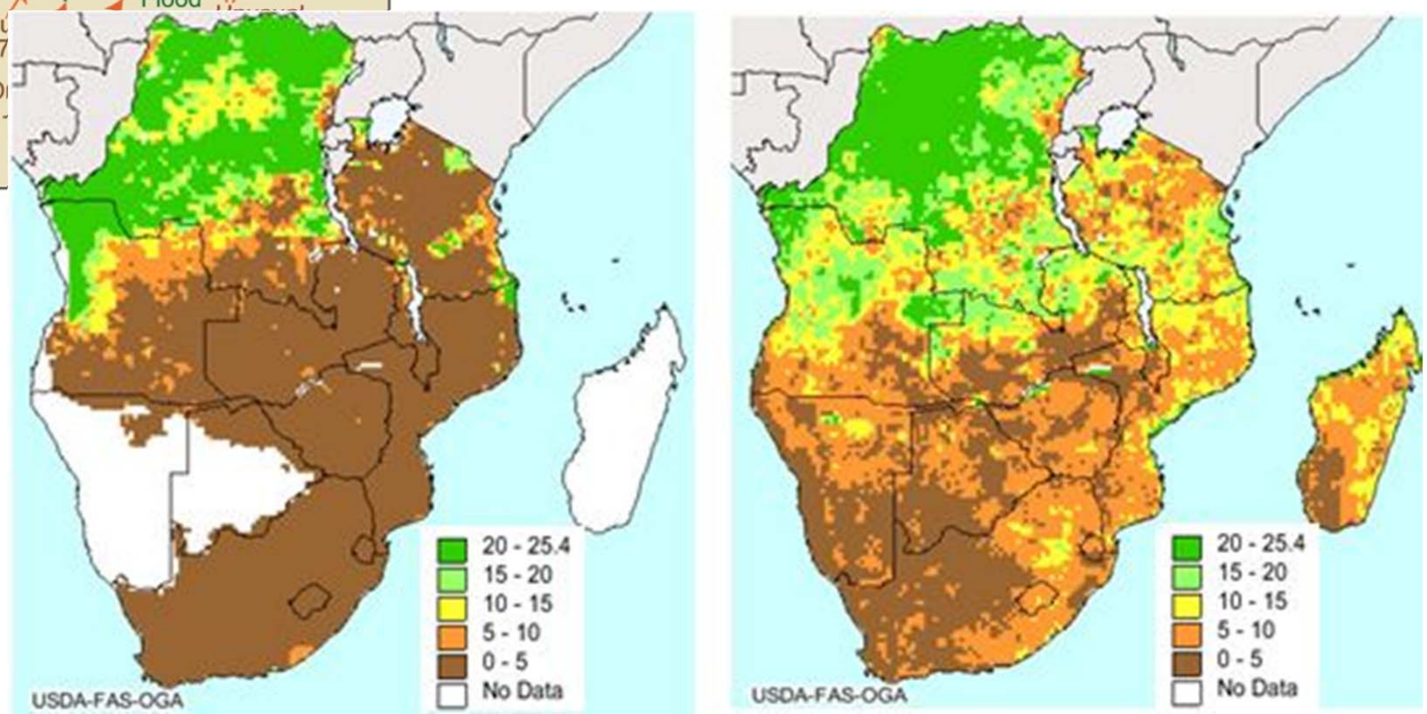
Al Bitar

FOOD SECURITY

SM data used to predict drought and improve crop yield by US Department of Agriculture, Crop Explorer website: http://www.pecad.fas.usda.gov/cropexplorer/



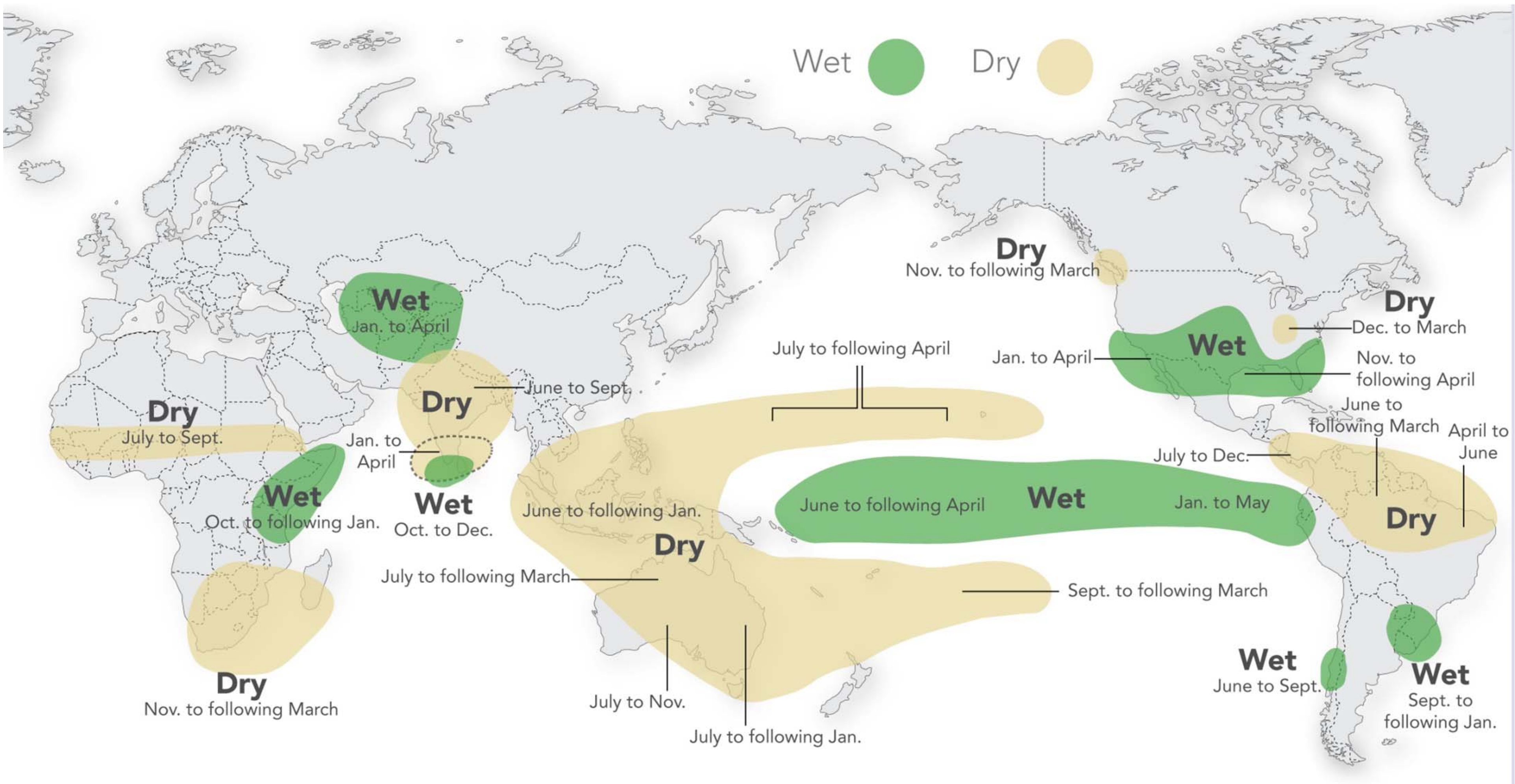
Credit: USDA FAS



Credit: USDA FAS, Soil moisture in southern Africa in mid-April 2014.

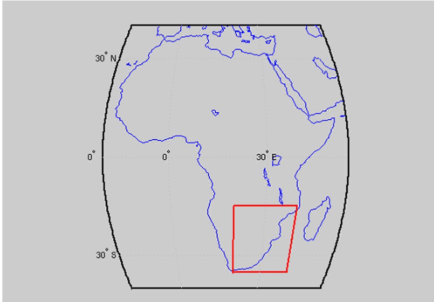
W Crow USDA

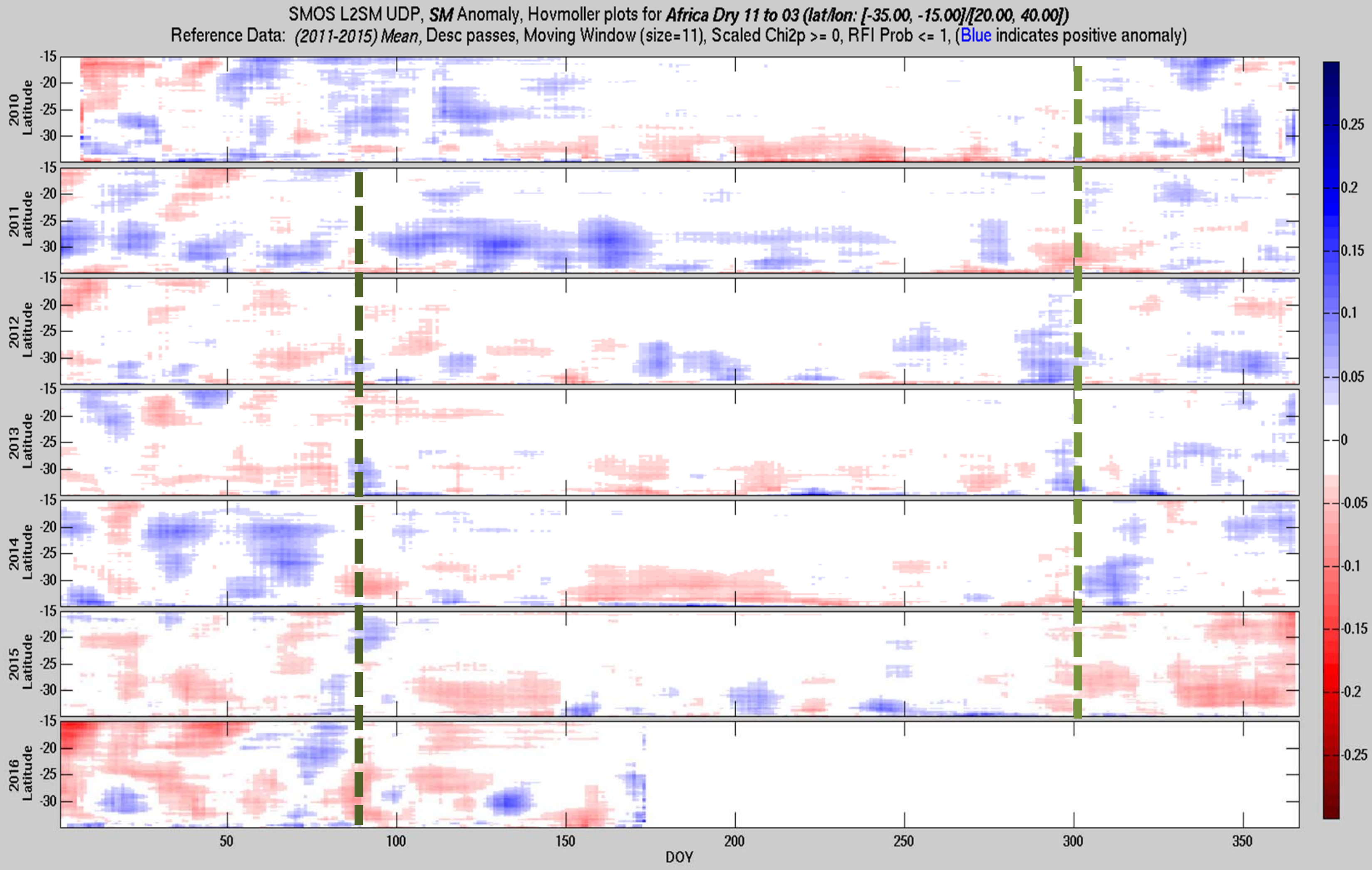
El Nino Impact



A. Mahmoodi

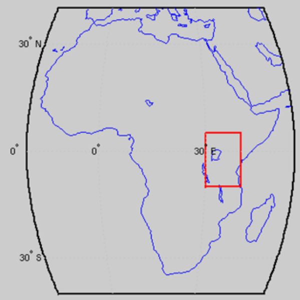
Africa South, Dsc
Dry 11-03

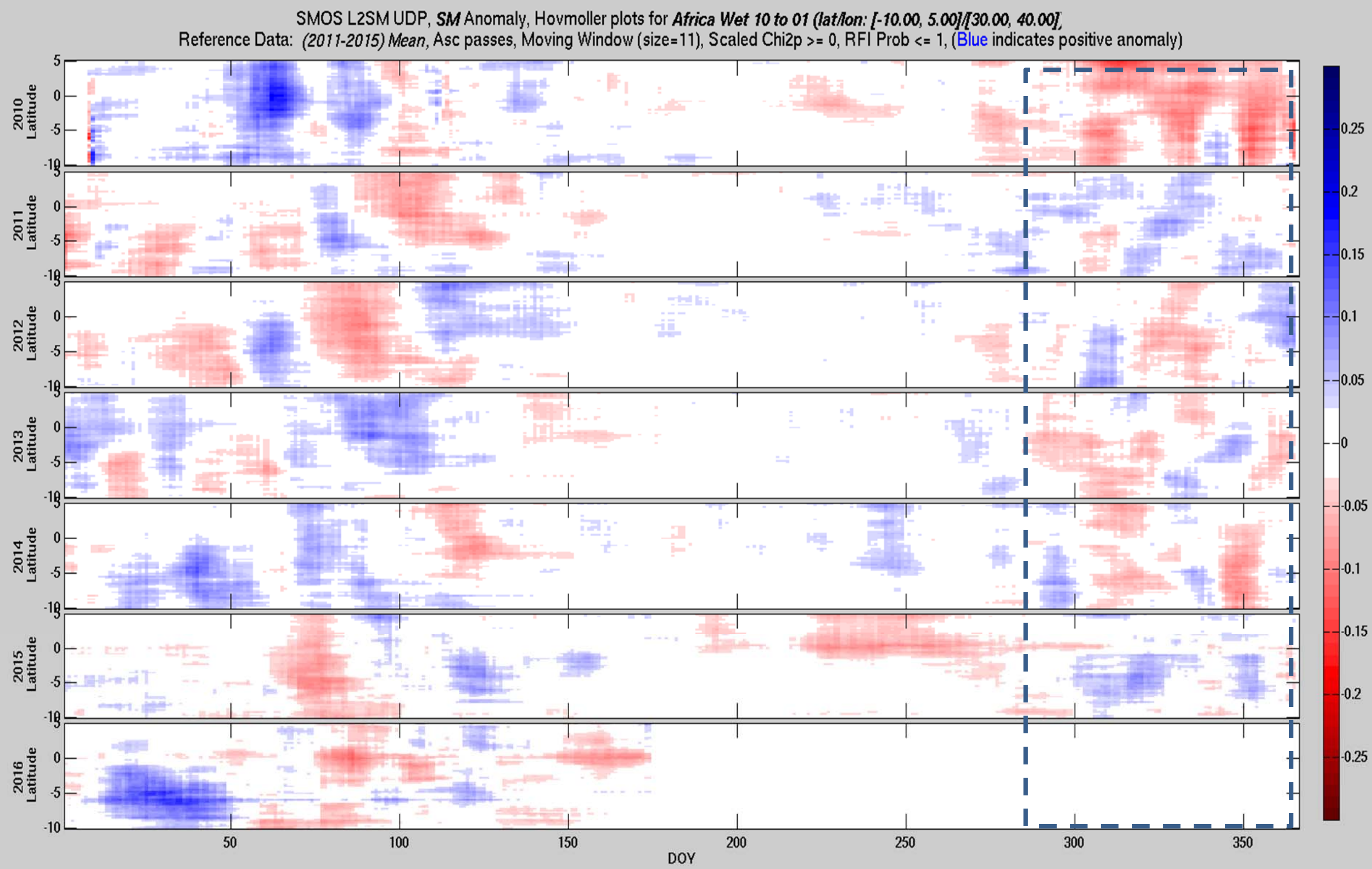




A. Mahmoodi

Africa (East), Asc
Wet 10-01



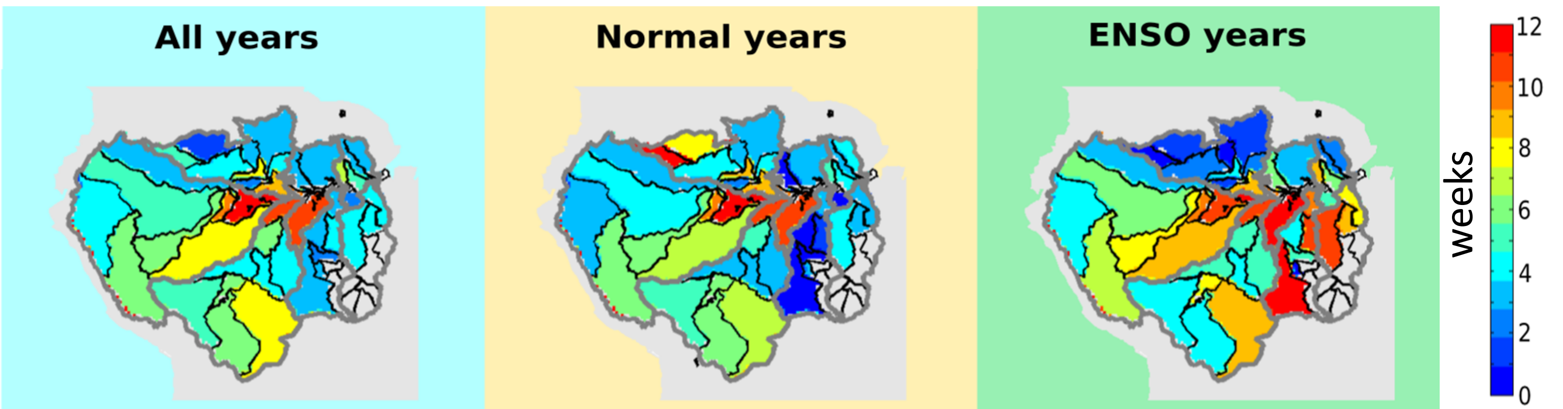


A. Mahmoodi

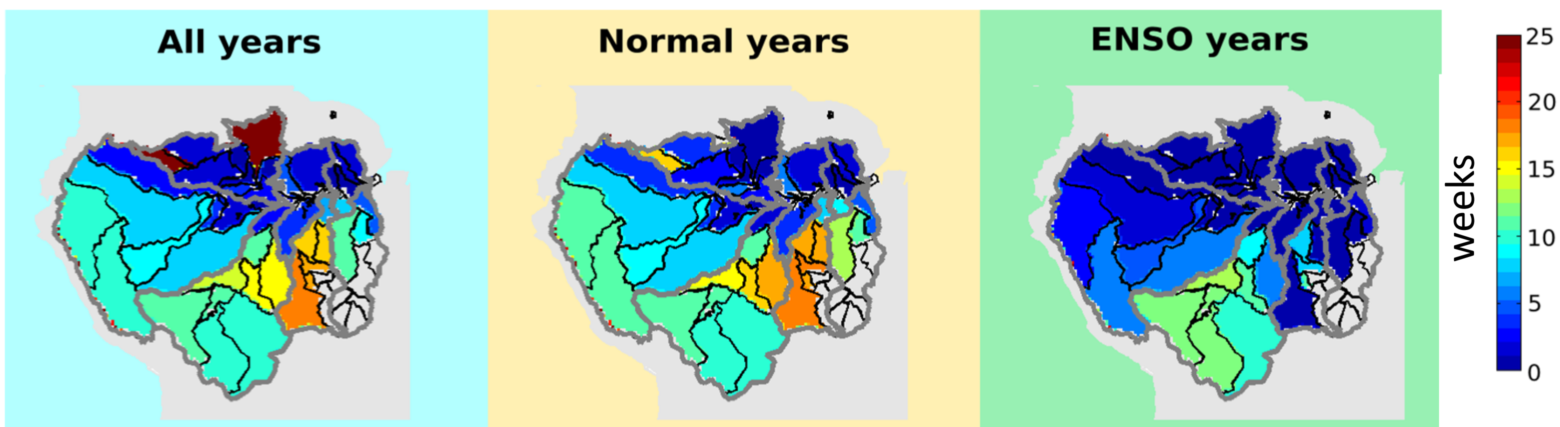
Observing ENSO's impacts on hydrological regimes with SMOS water fraction

A. Al Bitar, M. Parens

Time-lag between SMOS water fraction & TRMM rainfall



Time-lag between SMOS water fraction & in-situ discharge at outlet



So What?

- Facts
  - L band = New measurements not available before
    - Proxies not always adequate
    - New measurements → New science
      - A wealth of new results in very various fields
        - Land , ocean, cryosphere
  - Science oriented missions but
    - Many operational applications
      - Showing the real impact of this data set → undisputed gap filler
  - Main issue
    - Continuity
      - There are no real alternatives as of now
- Illustration/ examples

Comparison to root zone products

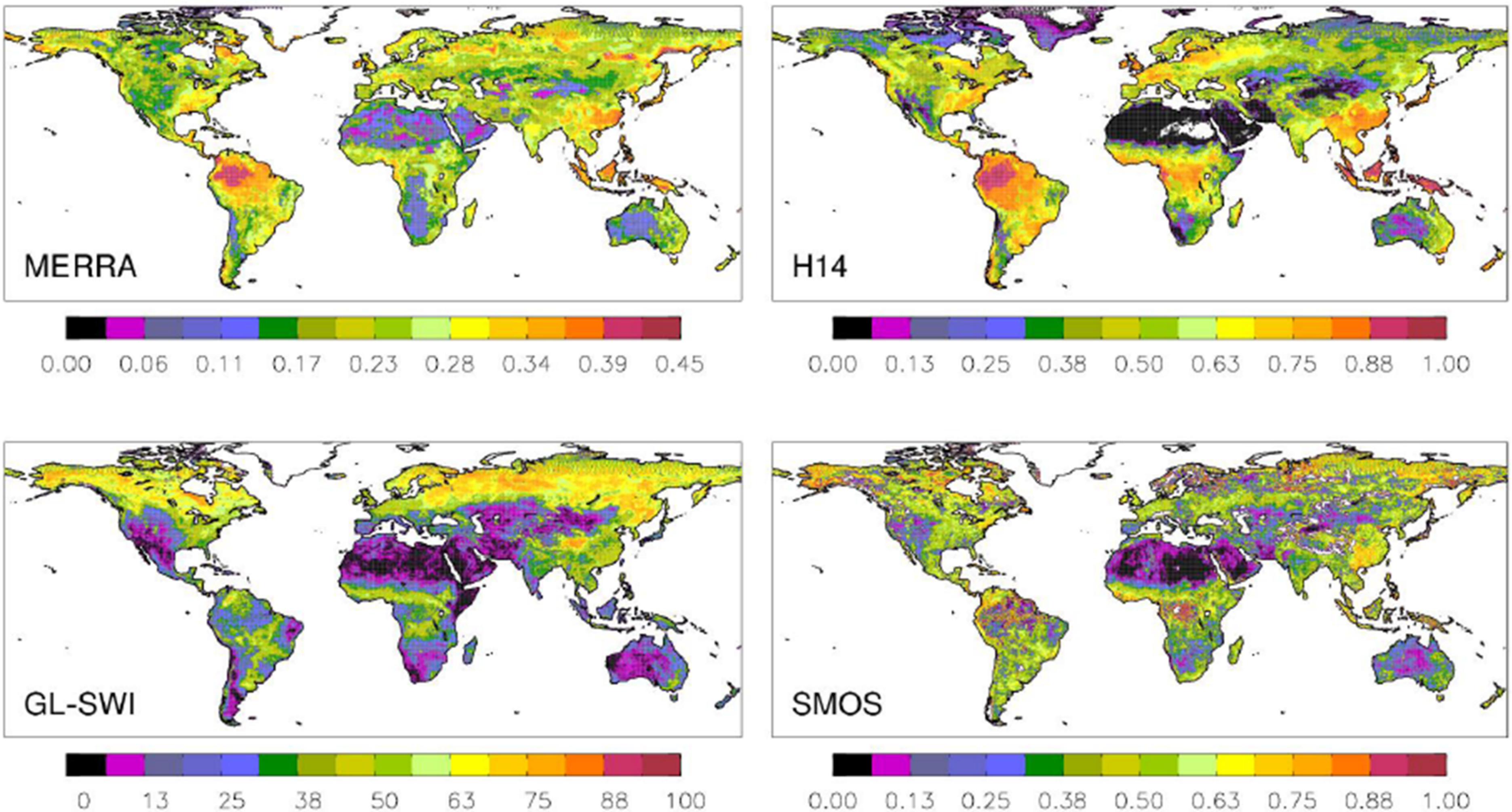
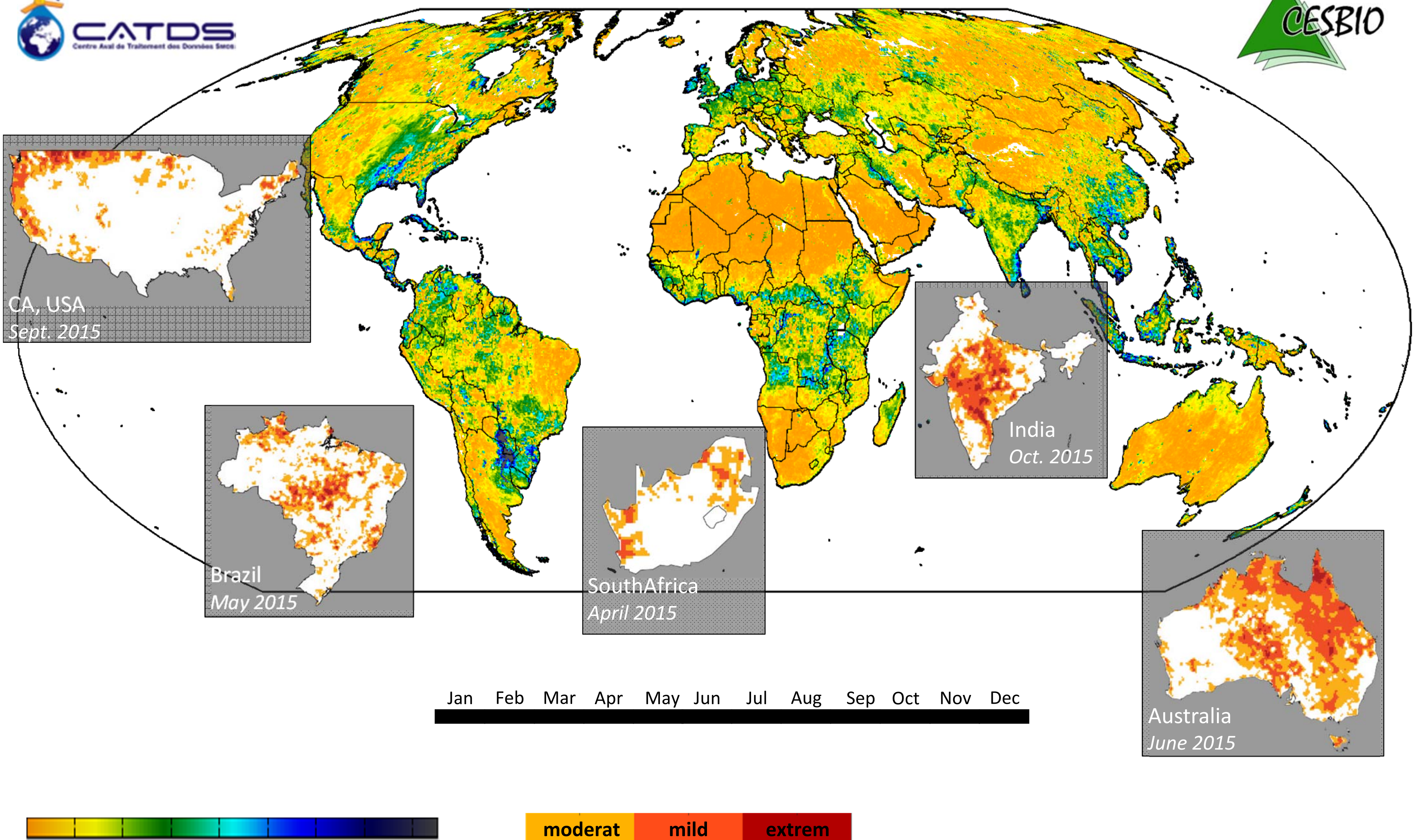


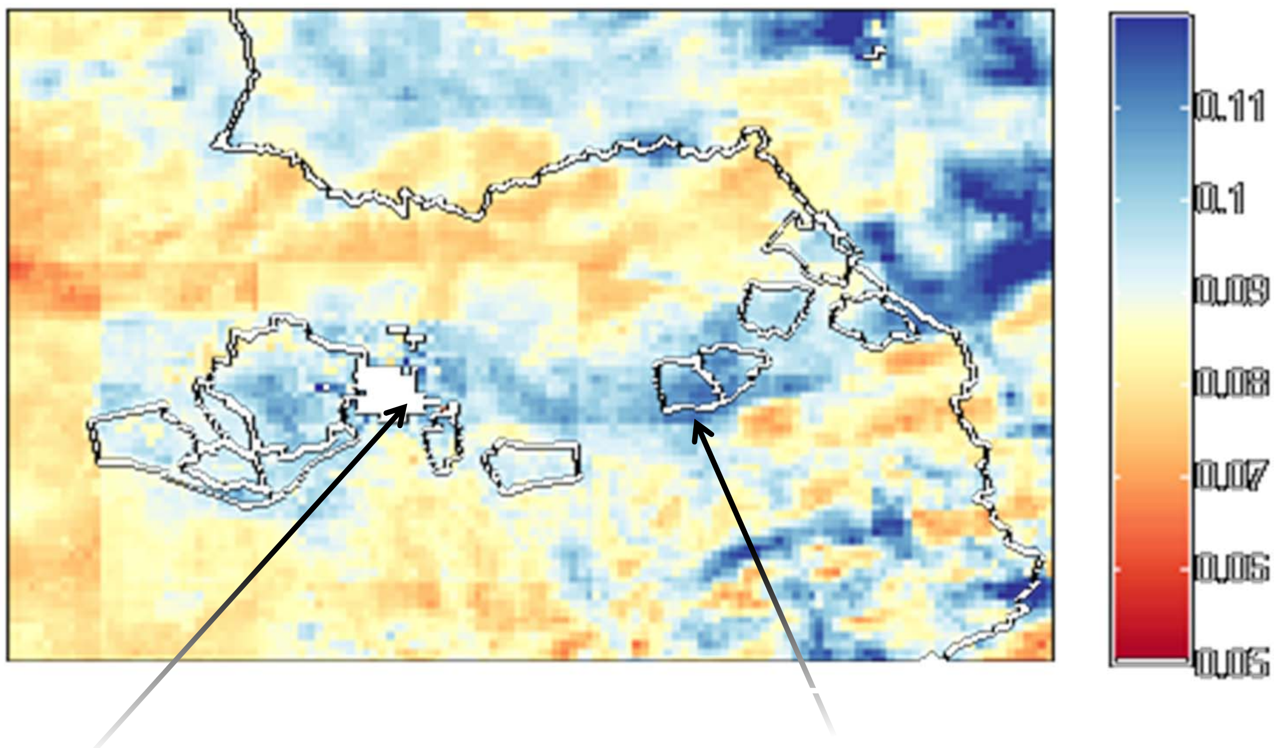
Figure 1: Annual mean root-zone soil moisture maps for MERRA, H14, GL-SWI and SMOS.

Pellarin, T., de Rosnay, P., Albergel, C., Abdalla, S., & Al Bitar, A. H-SAF Visiting Scientist Program HSAF_CDOP2_VS12_02, 2013.

SMOS monitoring 5 major droughts in 2015

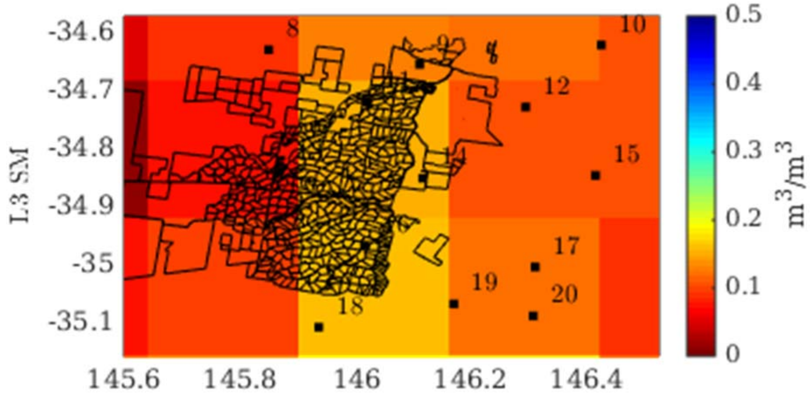


Soil moisture – Irrigated area



Irrigated area is well visible

Example of SMOS High Resolution data fo irrigation monitoring



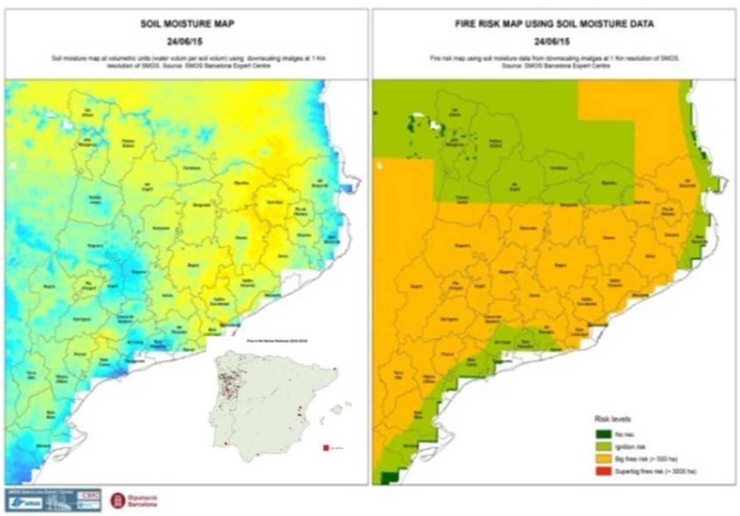
Molero et al

DOWNSCALING SOIL MOISTURE - *For agriculture (irrigation, crop monitoring), hydrology (flood forecasting) and fire risk monitoring*

Approach #1: SMOS and optical data (land surface temperature and Normalized Difference Vegetation Index (NDVI)), e.g. MODIS, Sentinel-3.

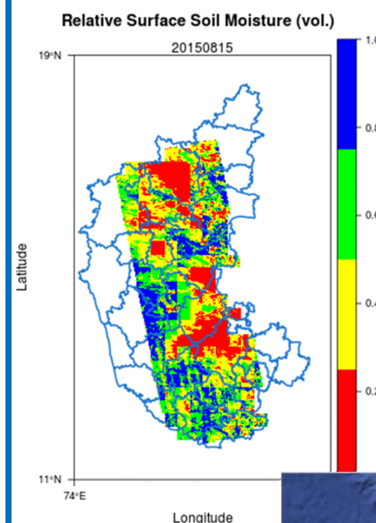
Data available from

- Barcelona Expert Centre: http://cp34-bec.cmima.csic.es/land-datasets, (Iberian Peninsula)
- CATDS www.catds.fr/Products/Available-products-from-CPDC (global maps – release planned July 2017)

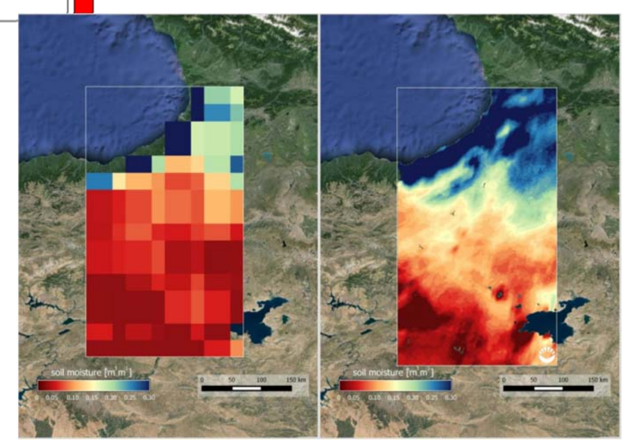


Forest fire risk monitoring – operationally used by Diputació de Barcelona; data by BEC.

Approach #2: SMOS/SMAP and SAR data, e.g. Radarsat-2, RISAT, Sentinel-1.



SMOS and RISAT over Karnataka, India; (Tomer et al., RS, 2015, 2016); sat@aapahinnovations.com

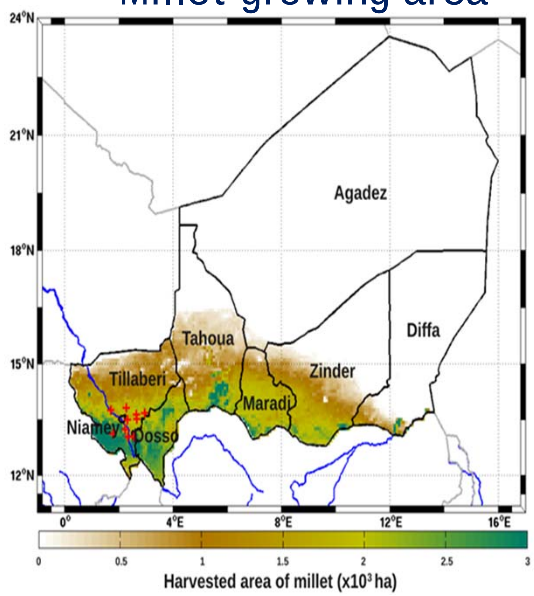


SMAP and AMSR and Sentinel-1: available from www.vandersat.com

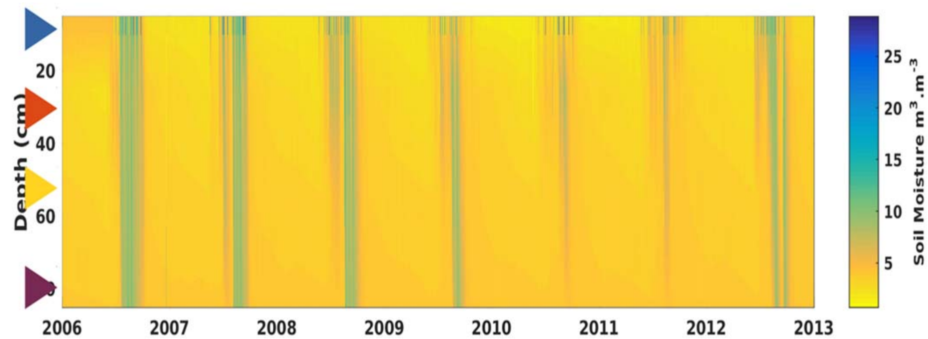
Yield estimate for Millet using SMOS data

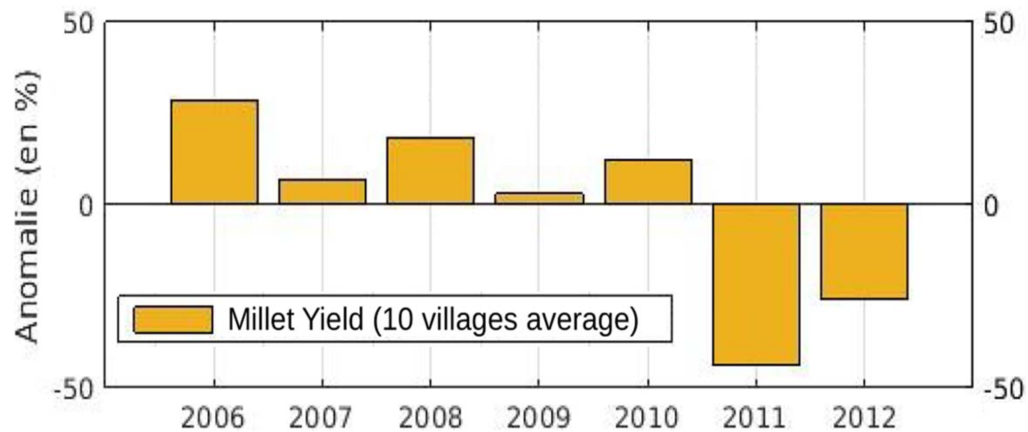
F . Gibon, T. Pellarin, C. Roman, C. Baron, A. Alhassane, S. Traoré, Y. Kerr

Millet growing area

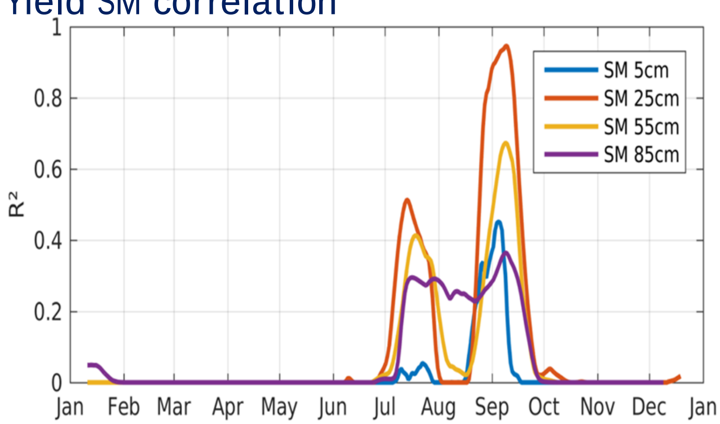


in-situ soil moisture



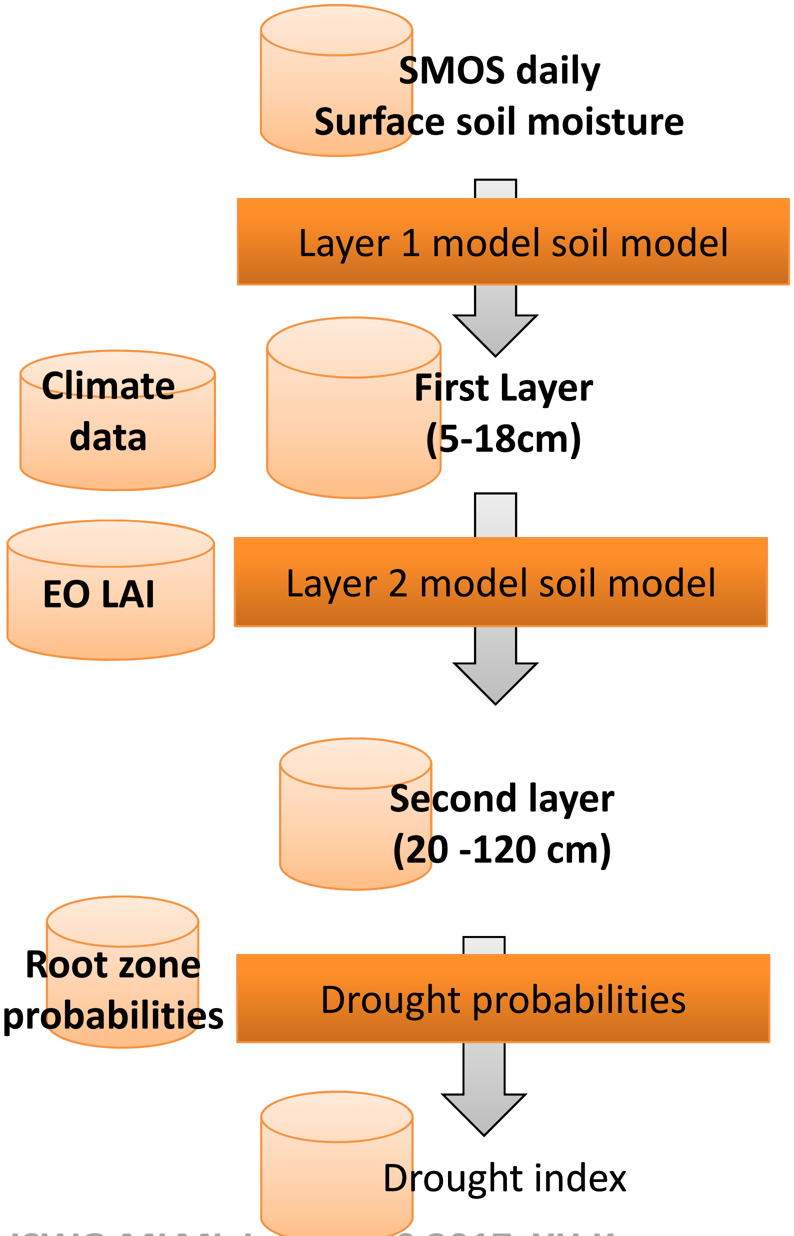


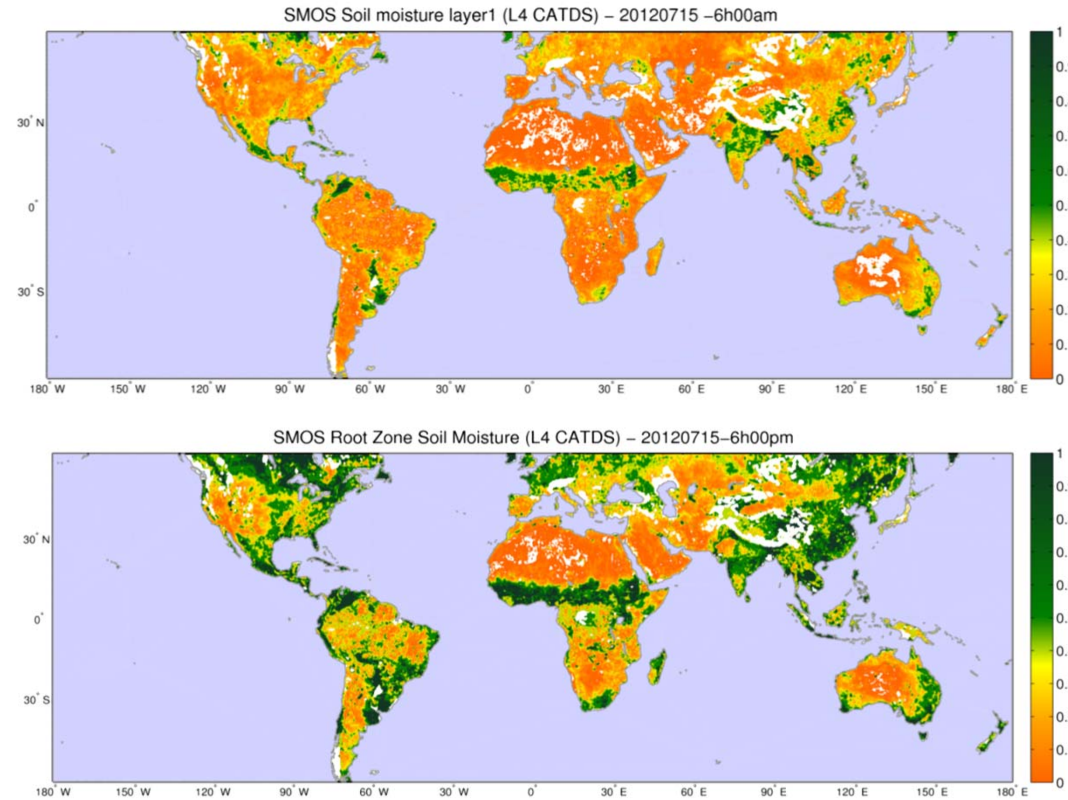
Yield SM correlation

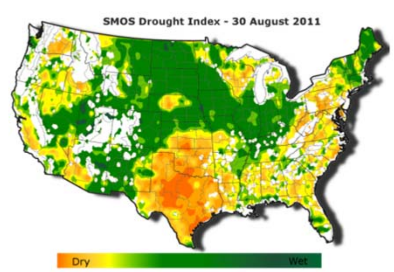


Very high correlation wetween yields and Root zone Soil moisture (at 30 cm) R=0.97

The approach







web application
+
Netcdf products :
EASE grid 25km

Al Bitar et al., 2013